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COAL AND CIVILIZATION

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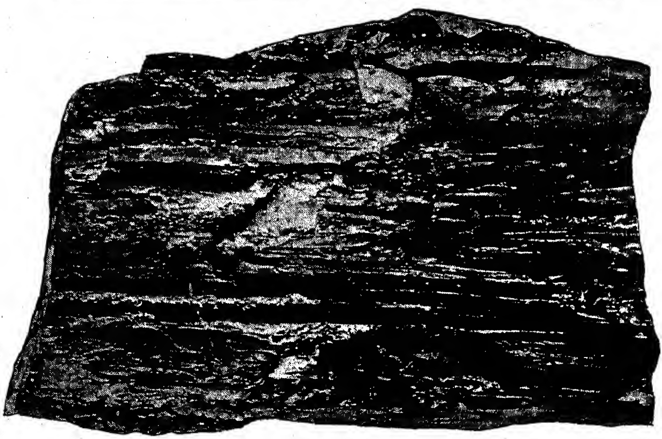

A.—Fragment of coal showing transition from bituminous coal to cannel.

B.—Striped coal showing the alternation of glistening and dull layers.

COAL *and* CIVILIZATION

BY

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To R. W. S.

LOYAL AND GENEROUS FRIEND

PREFACE

The present volume is planned for the use of two distinct publics. In the first place, it is considered of real importance to direct the general reader to the fundamental part played by coal and its products, such as petroleum, gasoline, dye-stuffs, explosives, etc., etc., in our modern civilization. The welfare and prosperity of nations, in this industrial age, is intimately connected with the use and exploitation of coal and its derivatives. Not only is national well-being intimately connected with coal resources, but the political future of great nations and races is likewise inevitably bound up with the same mineral. The problems of Europe are very obviously problems of coal. The so-called decadence of certain of the European races is clearly not due to any real degeneracy, but rather to poverty of resources in coal. This is notably true of the Latin races and is only less obviously the case for those Nordic nations which are without the indispensable mineral of our modern civilization. On the other hand the rise of Great Britain and Germany, in the past two centuries, is clearly and mainly bound up with the development of their great coal resources.

Further, the problem of coal cannot be appreciated

fully without a knowledge of the structure and mode of origin of this truly invaluable mineral. The writer, during the past two decades, has devoted much time and energy to the study of extinct plants, on account of their basal relation to any permanently valuable hypotheses in biology, which have to do with evolution. In the course of these studies, he had devoted much time to the devising of improved methods of investigation. In the past, our knowledge of extinct plants has been confined chiefly to the impressions left by these on the strata. More recently the petrified remains, which are all too rare, have yielded much valuable information as to the succession and nature of plants during the geological ages. There are great accumulations of carbonized remains of plants in the form of coals and lignites, which in the past have been virtually a sealed record to the investigator of evolution. The present author has succeeded in making these documents available for study by the development of new methods of investigation.

It was only natural that in the course of investigations on the carbonized remains of plants, the huge deposits of these, which appear as coal, should have received attention. Fifteen years ago, we knew virtually nothing about the structure of coal, with the exception of a few individual types which could be investigated by the methods used by the mineralogist and petrologist. Now all that is changed and we know the organization of all com-

bustible minerals from peat to anthracite, and are in a position, as a consequence, to put forward valid hypotheses as to the origin and modifications of the various types and ranks of coal.

Although the author cannot claim to be a geologist, he feels obliged to pay a tribute to the courtesy and helpfulness of his geological colleagues, who have not only supplied him with abundant materials for his investigations, but have also welcomed his results with often too generous praise. It has even been suggested by some of his German colleagues that an institute be established in that country to carry on work on coal with the "Jeffreyschen Methoden." This tribute must be regarded as particularly generous from a nation which, whatever may be its faults, has made more progress in the study and utilization of coal products than any other.

Harvard University,
20th of October, 1924.

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CHAPTER I

COAL AND CIVILIZATION

Civilization comprises the development of the arts, the accumulation of learning and the softening of manners. The two latter depend on the first for it is the growth and complication of the useful and the beautiful arts handed down from generation to generation, which makes learning advantageous and a necessity. The high degree of co-ordination and co-operation involved in the practice of the higher arts, naturally bring with them a softening and refining of manners, which to many minds is the outstanding characteristic of civilized communities. A further feature of civilization is the relative well-being of civilized communities, contrasted with those which are still in a state of savagery. Uncivilized man is at the mercy of the elements and the seasons. His more cultured fellowman to a large degree controls and equalizes the vicissitudes of nature.

Those communities which are in the best position, through natural resources and native skill, to practice the liberal and useful arts are, other things being

equal, the most advanced in civilization. Of all the resources which are basal to our existing civilization, the possession and utilization of coal must be placed first. The elaborate housing and heating, the complicated systems of transportation, the huge and manifold manufacturing activities of modern communities, all involve the high development of the metallurgical arts, which are based on the use of coal. The working of iron and other ores is fundamental to national well-being and those nations, which are lacking in adequate resources in coal inevitably must fall behind those which are abundantly supplied. The older civilizations all antedate the utilization of coal by man, which in reality began only in the seventeenth century of the Christian era. The cultures of ancient Greece and Rome waxed and waned before the advent of coal in industry.

The cramping influence on national prosperity, resulting from a scanty provision of the all important mineral coal, are perhaps nowhere so well illustrated as by the case of France. Her people are of exceptional intelligence and hold a high place in the practice of the arts of peace and war. France is financially in desperate straits and her birthrate has revealed this condition for more than a century. In 1801 there were 904,000 births in France and one hundred years later there were only 857,000. In 1907 the deaths exceeded the births by about 20,000. It can not be successfully argued that the decline in

the birthrate of the French nation is the result of a natural sterility for the French stock in the Canadian province of Quebec is characterized by a very exceptional fecundity, resulting from the more generous conditions of existence in a new country. France has less than one-tenth of the workable coal, which is found in the island of Great Britain and by reason of the scattered and scanty nature of her coal fields they can not in general be advantageously exploited so as to yield a generous supply of this indispensable mineral. The result is the crippling of the large metallurgical industries which lie at the bottom of the prosperity of the great nations. Further since war is always possible and since modern warfare involves the intensive use of coal for the manufacture of explosives, France is in a doubly desperate case, both because of her waning man-power and because she is inadequately supplied with the raw material of the most effective explosives. Both handicaps arise from the inadequate seams of coal within the national boundaries of the French Republic. Those who live under happier material conditions do not in general realize the difficult position of the French nation, exposed as it is, to constant menace from the fecund millions across the Rhine. In 1910 Germany mined two hundred and twenty-one million tons of coal, while France raised only thirty-eight million tons from her mines.

The case of Spain is only less striking than that of France. Her birthrate is only second in smallness

to that of her French neighbor. At the time of the discovery of America, Spain had a population of between seven and eight millions. At the present time her numbers are only about twenty millions. Great Britain even in the days of the Armada had a population less than half that of contemporary Spain. Now the peoples of the Island of Great Britain alone number more than forty millions. The present small population of Spain is all the more surprising, in view of the fact that she has great natural resources, except in coal, and when she was a Roman colony is authoritatively estimated to have supported a population approximating fifty millions. The Roman age was in fact the golden one of Spain and not even when her fleets of silver ships were being convoyed regularly from the western continent did she enjoy greater prosperity. That the failure to grow rapidly in population is not due to any natural or acquired sterility of the Spanish stock, is clearly shown by the prolific peoples of South and Central America, which have sprung from Spanish loins. The "A B C powers" are great and flourishing nations which have outstripped or will outstrip their mothers, Spain and Portugal.

In Italy we find a nation, which is peculiarly fitted to supply laborers to the rest of the world. The Italian navvy is strong and capable of enduring with equal fortitude either heat or cold. His mentality, as has been shown by the psychological tests, conducted in connection with the American army,

during the recent war, is in general very low. His usual origin is from Calabria and other southern provinces of Italy. He emigrates either temporarily or permanently in large numbers, both to other parts of Europe and to the New World. As is commonly the case with stocks of low living standards, his rate of reproduction is high and in marked contrast to that of the populations of higher class, from the provinces of the North, which have a relatively low birthrate. Although the Italian of the better stocks, is naturally a mechanic of originality and ability, the metallurgical manufactures, which would give large scope to his tendencies, are in general lacking or much restricted, by the very inadequate beds of coal which are found within Italian boundaries.

These obstacles to the material success of the Latin nations have been the origin of an ill-founded hypothesis of the decadence of the Latin stock. Ours is an age of coal and those nations which are not fortunate enough to live over seams of coal, are much at a disadvantage in the hurly-burly struggle for existence. New countries with sparse populations are able to do very well even without coal, by reason of their abundant forests and fertile virgin acres. No old nation under modern conditions can enjoy such prosperity as will insure a high continuous degree of material comfort as well as mental and moral efficiency, without adequate supplies of coal. The truth of this statement is well illus-

trated by the history of Great Britain. From the middle of the seventeenth to the middle of the eighteenth century, the population of that peculiarly favored isle, practically stood still. This situation is traced by competent economists to the exhaustion of the British forests, which had hitherto furnished fuel for her prosperous iron industry, based on the smelting furnace fueled with charcoal. During the century described England lost her supremacy in metals, which passed to countries still primitive enough to bristle with primeval forests. Only the discovery of the process of coking coal and of the hot-blast furnace, restored the former prosperity of England and enabled her to resume her earlier pre-eminence in the commerce of Europe and the World. The effect on the growth of population of Great Britain was striking and immediate. Not only did the home-staying population increase at an unusual rate, but there was a large surplus of population to people her colonies beyond the seas.

Some of the most serious problems of the old world are those involving the lack of coal. The troubles of Ireland are much more due to her small and not easily exploited coal-fields than they are to oppression on the part of the inhabitants of the adjacent island of Great Britain. It has been shown by Jevons in his masterly work on the economics of coal, that the population of the Highlands of Scotland has suffered from exactly the same economic disability as the Irish. Like the Irish, the

Highland Scotch have no coal and like the Irish and the Italians they have had to emigrate in large numbers to other lands. It has been indicated above that the difficulties between the French and the Germans are fundamentally based on the fact that Germany has a large supply of coal and can support as a consequence a rapidly increasing population. France on the other hand is not provided with the resources in coal, which are essential to the well-being of any modern nation, with a heavily populated soil and consequently her birth-rate is nearly stationary and she has neither man-power nor the raw materials of the high explosives, which are essential to national defense under modern conditions. The effect of poverty in resources of coal is also shown in nations of the Teutonic stock. Sweden and Denmark down to the end of the eighteenth century were important European powers but at present with the complete establishment of the Age of Coal, they have sunk into the second rank in spite of their energetic and able Nordic population.

CHAPTER II

THE COAL AGE AND OTHER AGES

THE earlier and unwritten history of the human species is recorded only in impersonal and circumstantial documents. The Old Stone Age is revealed to us by its weapons of chipped flint supplied by ancient burying places, kitchen middings and cave dwellings. It was at the beginning of this earliest and most ancient cultural stage, the Old Stone or Paleolithic Age, that our race emerged from its ape-like ancestors and began to assume human traits. The Paleolithic period was very long and reached back at least to or even included the last glacial age, that is, from twenty to perhaps two to three hundred thousand years ago. Then followed the much briefer Neolithic or Polished Stone period, in which the human race learned to smooth its weapons and its utensils though not its manners. Later came the Copper-Bronze Age, when the sons of men became able to smelt and fashion copper and later discovered that the addition of tin produced bronze weapons and tools of better quality and, unlike pure copper, capable of being cast in closed molds.

The Late or Neolithic Stone Age, although indifferently supplied with efficient weapons and tools, has produced notable monuments both in the East and in the West. The first great pyramid of Egypt, covered with dressed granite blocks of over fifty tons in weight, was built by a people who had not yet reached the bronze stage of culture and it is doubtful if they had even copper tools to work the hard stones of the earlier Egyptian pyramids and temples. It is interesting to note in this connection that Cheops (4th dynasty), the builder of the first great pyramid at Giza, reigned at a period three times as remote from the Christian era as Tut-ankh-Amen (18th dynasty), whose tomb has recently excited so much attention, in other words, from six to seven thousand years ago. In the British Isles, France, Portugal, etc., the Late Stone Age is commemorated by great circles and colonnades of huge single stones or monoliths. Even the later temples and monuments of Egypt, were for the most part fashioned with implements of stone, copper and bronze.

Iron became the all important material for the manufactnre of weapons and implements about a thousand years before the beginning of the Christian era. Around the eastern part of the Mediterranean, the use of iron was probably earlier, while westwards toward the Pillars of Hercules and the British Isles its manufacture was later known. The more modern civilizations belong to the Age of Iron. In

this period the warlike activities of our species (unfortunately, then, as now, predominant), as well as its industries, were carried on by weapons and implements fashioned of iron and even of steel. The age in which iron and its elaborations dominated the advanced culture of mankind, continued down until about the middle of the eighteenth century of the Christian era. The classical, medieval and modern phases of European history belong to this period. During all the centuries from the Greeks to the coming of the Hanoverians into England, weapons and tools of iron and steel were relatively few and costly although often of the highest quality. The only method of winning iron from its refractory natural state, was by means of the charcoal furnace. The forests of Europe disappeared in the insatiable maw of its iron forges and the art of smelting was finally compelled to take refuge in outlying countries like Ireland and Sweden, where the primeval forests had been less ravaged by the hand of man. The scarcity and dearness of iron and steel greatly hampered the progress of our race, towards the end of this period, and the population of the British Isles remained nearly stationary for the hundred years ending about the middle of the eighteenth century.

The practical application of coal as an efficient substitute for charcoal, in the smelting of iron, marked the opening of a new epoch in the world's history,—the Age of Coal. This era had its begin-

ning in that country naturally endowed with the most abundant and the most workable coal, namely, Great Britain. Although coal had been used under the name of pit-coal or sea-coal, by the less fastidious householders for heating and other domestic purposes, in the later centuries, when the primeval forests had begun to grow thin under the increased ravages of man, it had small place in the industrial arts beyond its use in the blacksmith's forge. The middle of the eighteenth century saw the establishment of the blast-furnace and the probable development of coke derived from coal, in place of the vanished supply of charcoal, originally used for smelting iron. In the following century the hot blast was invented by Neilson, with a consequent reduction of the amount of coal necessary to transform iron ore into a ton of the finished product, from seven to two tons. The effect upon Great Britain was tremendous. Her commerce and her industries increased enormously, and her population, which for nearly a century ending about 1750, had practically stood still, assumed now a rapid rate of growth, which it maintained down to the recent World War. It is interesting to note that the general increase of the nation was large enough to provide not only for a considerable regular addition to the resident population, but also for a huge emigration to the British Colonies and to the United States. The increase, significantly enough, was strictly confined to industrial and particularly to coal-mining

districts, as Jevons has admirably shown. Regions without workable coal, such as Ireland and the north of Scotland, which were consequently preponderantly agricultural, lost a great part of their population by migration and emigration. The population of Ireland was in fact reduced by nearly one-half, in the years following 1850. This is sometimes attributed to political conditions in the case of Ireland, but this can scarcely be the real explanation since the north of Scotland suffered to practically the same extent, and by reason of the same economic cause.

The late nineteenth century and the opening years of the present century have seen the overwhelming dominance of coal in our civilization. Coal is now not only the basis of all the metallurgical processes, basal to our modern civilization, but likewise affects our lives fundamentally in many other ways. Our dwellings are heated either by coal or its immediate derivatives. The high explosives of modern warfare are mainly coal products. One need only name trinitrotoluol, lyddite, melinite, etc., to establish this truth. Our disinfectants, our unguents, and many of our most important medicines are likewise derived from the dry distillation of coal. The coal tar colors, which have entirely revolutionized the dyeing processes of our forefathers, are another illustration of the indispensable character of this product of the earth. Electric light carbons, tar, pitch, creosote, lamp-black, printing ink,

naphtha, gasolene, kerosene lubricating oils in great variety, paraffine wax, etc., are only a few of the invaluable products derived directly or indirectly from coal.

The progress of events has in fact brought it about, that the nations which are in possession of abundant supplies of coal are in the position of unquestionable industrial supremacy. The consumption of coal *per capita* of the population supplies a very reliable indication of the wealth and prosperity of a nation. It is in reality much more significant in this respect than the possession of mines of precious minerals and precious stones, for the ownership of coal, coupled with a reasonable degree of national efficiency, makes all other purchasable products easily available. Just before the World War the annual *per capita* consumption of coal by the United States and Germany was about five tons, while that of Great Britain was nearly seven tons. There is little reason to doubt that the nations of North America, the United States and Canada, will during the twentieth century come to enjoy the striking commercial position which has belonged to Great Britain during the past hundred years or more. Natural oil and natural gas are likely to have very little general effect on the situation in the long run, as the supplies of these are too ephemeral and uncertain to be of great significance except from the standpoint of the winning of private gains. It will be unfortunate if any of the great nations allow

their international relations and policies to be permanently influenced by the desire to possess or dominate oil fields. The attitude of the United States toward Mexico in this respect seems to be based on considerations of sound policy and it is only to be hoped that a similar wise self-restraint will govern her relations to the rest of the world, in the matter of oil.

The origin of coal and the relation of its composition to its various uses in the arts and industries have until very recently been largely unknown. It has been the task of the geologist to inform us as to the conditions of occurrence and the extent of beds of coal, but the fundamental problem of the structure of coals is one which is quite beyond the usual methods of the geologist. It is possible for him to describe the rocks which support the coal beds from below and cover them from above, but on account of the blackness of the substance of the coal itself, the geologist has been able to supply little real and reliable information concerning its composition or origin. Since coal is now universally admitted to be of vegetable origin, it seems not unlikely that the special student of plants will be able best to illuminate this very dark subject. It further seems reasonable to expect that the opinion of the trained student of plants in the diagnosis of the substance of the all-important combustible minerals or coals, should be as worthy of respect as his identification of a fossil tree from its

woody organization when its leaves, seeds, and other features of external recognition have disappeared. Stratigraphical geology is in no better position in regard to the study of coal, in fact, than a reader would be in regard to the contents of a book bound in misleading covers and sealed with seven seals. The geological theories in regard to coal are in consequence often as fantastic and as little founded on known facts as is frequently the case with political or religious opinions. It is the purpose of the present modest volume to describe the structure and the mode of formation of the more important deposits of vegetable matter, and by the comparison of these with the actual organization of the various coals as ascertained by recently developed methods, to show how our coal deposits have been formed, and the relation of their uses in the various arts to their fundamental composition.

CHAPTER III

THE HISTORY OF A LAKE

It is impossible to understand the structure of coal or its mode of formation without knowing something of the manner in which lakes are formed and later filled with vegetable matter. Hollows in the surface of the ground are due to many causes, but those in temperate regions were mainly caused by the action of ice in the last glacial period. The resistless force of the ice-rivers or glaciers has dug out cavities, which later became filled with water from the melting ice or by precipation from the clouds. In strongly glaciated regions these lakes are very numerous and in New England are a constant and attractive feature of the landscape. For a time after the retreat of the ice to its northern strongholds, following the melting of the ice-sheet, which covered the country down to the latitude of Cape Cod, the trees and other plants lingered in the south, whither they had retreated during the Ice Age. Very slowly they came back and they were preceded by lower forms of life owing their propagation to spores, readily floated through the air or carried in the plumage of birds. The slower march-

ing seed-plants in general took centuries to advance over any considerable distance, particularly the late-breeding trees. As a consequence of this condition we find evidence of the presence of lower forms of plants in lakes long before the forests returned in diminished numbers, after the Ice Age, to their ancient seats. As a result of their organization, these lower plants for the most part disappeared without a trace, particularly if they were water plants. Of the lowly forms, which peopled the reviving lakes, some accumulated quantities of mineral matter in their bodies. In regions where the granitic or similar rocks occurred, large quantities of minute water plants known as Diatoms are found. The bodies of these were protected by two flinty shells fitting together like the bottom and lid of a cardboard box. When the small inhabitant of the box ceased to exist, its characteristic shell sank to the bottom of the lake. In the course of years countless millions of these untenanted cases accumulated and they formed a layer often a foot or more in depth on the floor of the lake. In very deep ponds the accumulations of this character may become very considerable and are commercially valuable as polishing powders or as the raw material of germ-proof filters. Where the country rocks are limestone, as is the case in more fertile regions, the abundant lower water plants are the Stoneworts. These are rooted to the bottom of the lake and do not follow the

free life of the Diatoms. As a consequence their remains do not occur in deep water. The bottom of standing bodies of water in such regions is often occupied by a foot or two of white marl, composed of the calcareous bodies of the Stoneworts. In this are frequently entombed the shells of species of water-snails and other parts of small animals, with occasional bones of fishes. Intermingled with the mineralized remains of both Diatoms and Stoneworts, are the spores of lower land plants,—Ferns, Mosses, Horsetails,—as well as the flinty skeletal parts of fresh water sponges. Sooner or later the presence of trees becomes evident under the waters. The bottom slime or plastic mud of lakes and ponds, when examined under the microscope in its upper portion, reveals the presence of the pollen or blossom dust of Pines, Spruces, Larches, etc., clearly showing that these trees had returned from their long sojourn in the South. Later comes the pollen of deciduous trees,—Alders, Birches, Willows, and others loving the vicinity of water.

In the accompanying illustration is shown the upper portion of the fine black mud from a lake bottom as seen under the microscope. Several dark masses of some size are visible, which represent the ejecta of fishes or frogs and perhaps the slime of certain water plants. Together with the formless masses are seen smaller bodies which have an obvious structure. The smallest of these are the pollen grains of Spruces. Those of intermediate size be-

long to the Pines, while a single large grain comes from the balsam or Christmas-tree Fir. It is easy to observe the origin of such deposits in the New England June. Where the ponds and lakes are still girdled by their forest belts, the opening summer

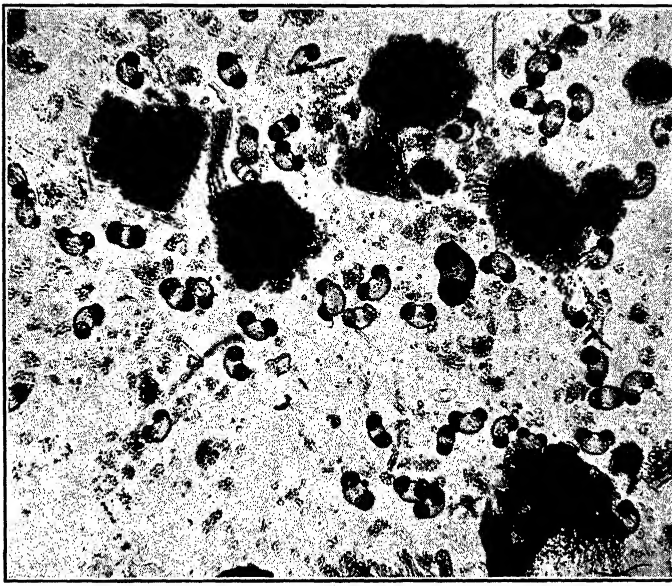

Fig. 1.—Magnified view of muck from the bottom of a lake showing pollen-grains and ejecta.

shows their surface covered with a yellow dust, which is popularly called "sulphur showers." The "sulphur" is not however what it seems to be, but is the yellow blossom dust of the surrounding trees and shrubs of the forest, shed over the sheltered bosom of the lake.

The next illustration represents some pollen of the white Pine, highly magnified under the microscope. Each pollen-grain is composed of a central body with two air chambers attached. The possession of the air chambers makes it possible for the

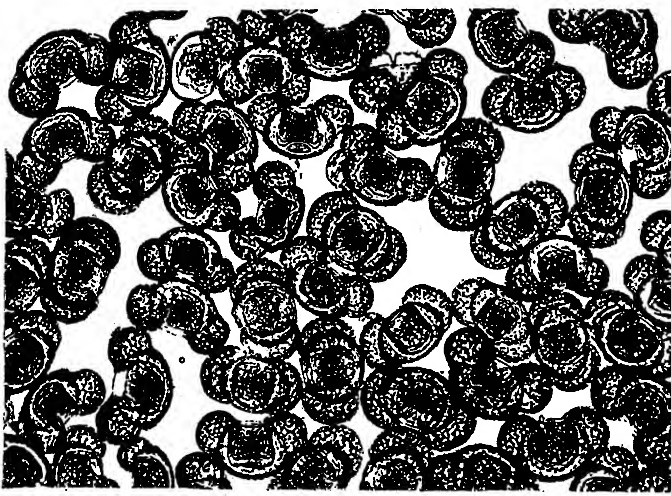

Fig. 2.—Highly magnified view of pollen-grains of the pine.

pollen to float in the air like a balloon, and there is one known case, described by Dr. Engelmann, where such blossom dust flew four hundred miles up the valley of the Mississippi, under the impulse of the wind, to be precipitated in an early spring shower on the streets of St. Louis. In later months other pollens become abundant, which owe their capacity for flight not to air sacks, but to their small size,

like that of fine dust. Incredible as it may seem, an important agency in the filling up of lakes is the air-borne pollen of plants. This condition is an exemplification of the importance of the exceeding small in the activities of Nature. An examination of the bottom of almost any pond or lake, with appropriate apparatus, establishes the fact that it is gradually filling up with organic mud or muck, which is mainly composed of air-carried pollen and the ejecta and bodies of water animals and plants. After the filling has proceeded to a certain depth,—supposing the lake to be originally deep, higher and seed-bearing water-plants, such as water-lilies, etc., are able to find a footing. After growing for a while on the bottom, they reach such a size that they are able to send their leaves and flowers to the surface. Pondweeds, water buttercups, milfoils, honeworts, water-stars, arrow-grasses, Vallisnerias, etc., etc., likewise flourish under these conditions, but on the whole the most successful water plants of moderate depths are the various species of white and yellow water-lilies, since these are gross feeders and rapid growers. One would be inclined to suppose that a considerable amount of earthly silt would be intermingled with the vegetable and animal substances described above. In a condition of Nature, however, this is not generally the case. There are two reasons for this. First of all, under natural conditions the lands are covered to such an extent with vegetation that their surface is not readily reached by erosive

agencies. In the second place, accumulations of vegetable matter in considerable amounts only take place in quiet water. Material derived from plants, on account of its greater buoyancy, sinks more slowly than does mineral matter, and thus even when the latter is present, it generally finds a different resting place.

Even when the lakes have reached what may be called the water-lily phase of sedimentation, the pollen showers continue to fall each spring and summer, and when the frosts kill down the lily-pads in the autumn, the more or less macerated remains of their leaves are added to the black muck of the lake. These remains are very characteristic and are so easily recognized that one can readily infer the degree of filling of the lake, even after it has become dry land, from the occurrence of parts of water-lilies. We find now a condition where the waters are occupied during the summer and fall with a tangled mat of water plants, which continue to live on even after the forests on land have shed their summer coats in the chill winds and rains of autumn. Some of these water plants indeed are able to carry their leaves through the winter. The fall of the leaf on land, and the lashings of the autumnal gales, bring large contributions of foliage and twigs into the waters, which become entangled with the persisting water plants, until they waterlog and sink. In the following spring the "sulphur showers" rain down once more. At this stage, the lake muck consists not

only of blossom dust of manifold trees, shrubs, ferns, etc., and the relics of water plants, but also of coarser parts derived from the vegetation of the surrounding lands. The accompanying illustration shows a slightly magnified vertical slice through the

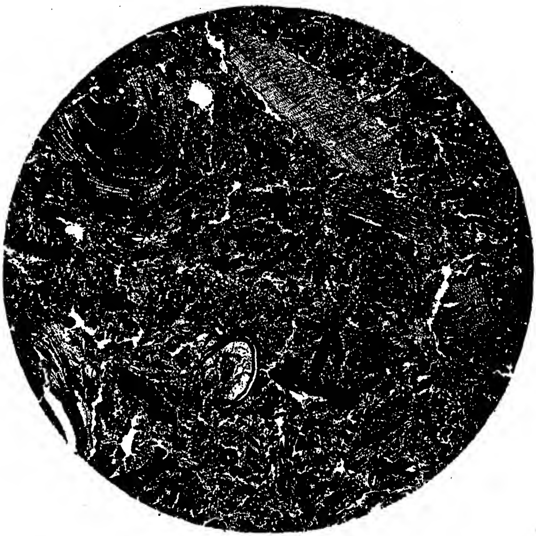

FIG. 3.—Peat accumulated in the upper layers of a filled lake. Low magnification.

upper layer of a lake almost filled. The coarser materials are in general the branches and leaves of land plants, and the finer matrix consists of more minute constituents,—pollen and the relics of water plants, etc. The next photograph shows the upper part of the last illustration under a higher magnification and makes it clear that the coarsest portions of

the filling material are woody in their character and come from plants on land. Through this mass penetrate delicate roots of water plants and the finer and coarser roots of such adjacent land plants as are able to grow in a watery soil. The lake muck is thus consolidated as it reaches the surface of the

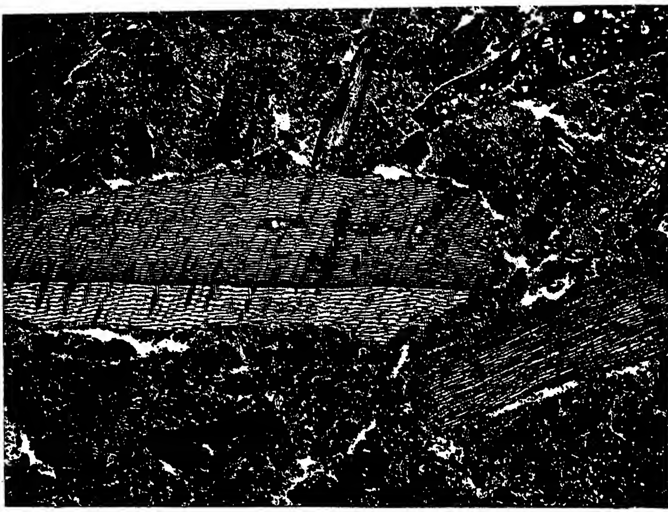

Fig. 4.—Upper part of Fig. 3 more highly magnified.

water and is able to resist the lash of the waves to which it is now exposed. At this stage or before it, spores cease to be deposited on account of the growing restlessness of the waters and their increasing shallowness. On the low lying coarse organic soil just described, sedges, grasses, blue-flags, catstails, and other amphibious vegetation are able

to gain a foothold. These flourish and die down with the changing seasons, and their bodies decaying slowly in the moisture-saturated soil gradually further raise its level, so that it becomes the substratum for heaths and similar forms. These are in turn followed, as the surface of the organic soil continues to rise, by conifers, such as spruces, larches and pines, while these may yield place later to deciduous trees and larger shrubs, such as birches, alders, gums, dogwoods, etc. A variation of the course of events may be supplied at any stage of the filling of the lake, by forest fires. After such catastrophes the charred remains of plants are washed or swept into the waters and for a year or two give a new character to the accumulations. In many obliterated lakes, the use of probing instruments shows the presence of charred fragments at various and often numerous levels, indicating relatively frequent conflagrations, which, however, need not necessarily have entirely destroyed the surrounding forests. Often in such cases, it is only the underbrush which is burned, while the larger trunks are left practically intact.

The stages in the filling up of a lake are diagrammatically represented in the accompanying illustration. The profile of the land is abrupt on the left of the illustration and gradually sloping on the right. On account of the indicated configuration, the accumulation of muck is much more rapid on one side of the water than the other. The granular material represents the first fine muck which is laid

down while the water is still relatively deep. Then comes the more fibrous muck consisting first of remains of waterlilies and sometimes other water-plants, embedded in a fine matrix. From now on the accumulations become more and more coarse and contain an increasing proportion of vegetable remains washed or wafted from the lands. The fibrous

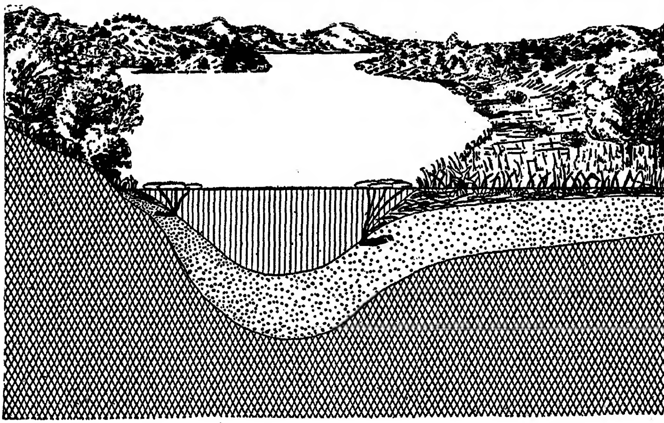

Fig. 5.—Diagrammatic view of the filling of a lake by vegetable remains. Full description in the text.

material which resists the wash of the waves, appears as a broad shelf, which is invaded successively, as has been described above, by amphibious herbs, by water-loving heaths, by conifers, and finally by deciduous trees. The lake is thus more and more encroached upon by vegetation. The march of the forest is rarely equal from all sides since progress is usually locally favored by shallow water, the prevail-

ing winds, and the direction of shelter. In the end the lake may become entirely obliterated and replaced by a forest or a heath. The origin of the floor of the forest or moor, can always be detected by the moat-like zone of water which surrounds it in the early spring or late fall. This is due to the rising and falling of the filling mass of vegetation resulting from the greater or less saturation of its substance with water. The material continues to increase by the fall of leaves, branches, etc., from the growing trees and shrubs. This stage is the *in situ* phase and the amount of vegetative matter added during its progress, compared with the open water or transport phase, is proportionately small. The late Dr. C. A. Davis, who made a very extensive study of vegetable accumulations in the United States, asserts that the accumulations of such material in open water (transport deposition) are greatly in excess (nine to one) of those laid down in the peat bogs (*in situ* deposition). Naturally if a lake in the process of filling becomes a peat bog, typical peat will constitute the upper and relatively shallow portion of the deposit.

CHAPTER IV

WATER AS A PRESERVATIVE

It is known to all that wood is subject to decay through the action of certain lower organisms. These organisms are highly effective in the presence of moisture, air, and a high temperature, and as a result, are very active in humid, hot climates. A railroad tie of good white oak will last in the cool temperate regions for six or seven years, or even longer. In the rainy tropics, the life of a white oak railway sleeper is scarcely six months. In other words, its destruction by wood-rotting organisms is more than ten times as rapid as in temperate climates. If wood and others parts of plants are kept continually submerged by water, their persistence is infinitely prolonged. The piles of Roman bridges and causeways are frequently disinterred in Europe in a perfect condition of preservation after many hundreds of years, provided they have, during all the interval from the time of their installation, been kept continually covered by water. An excellent example of the preservative power of water is furnished by the piles which served as the foundation of the Campanile in Venice, a city established in the Middle

Ages, on the mud-flats of the Lido, in order that its inhabitants might be safe from the ravages of the Huns. It was necessary to drive piling as foundations for the buildings, on account of the insecure substratum. The Campanile, as the loftiest and in relation to its base the heaviest building of Venice, was built in the thirteenth century. Not many years ago, this famous architectural monument collapsed. It was at first supposed that the downfall was due to defective foundations, but an examination of the poplar piles driven in the thirteenth century established the fact that they were as sound as when first put into place. The destruction of the building proved to be the result of too great stresses on the parts above the base. When it was rebuilt, the original foundations of wood were again utilized. So effectual is water as a preservative of wood, that wooden piles kept continuously wet are regarded as a permanent structure and often outlast the massive edifices of stone or brick which are reared upon them.

It follows from what has been stated above that remains of plants covered by the waters of lakes which maintain a reasonably constant level, persist unchanged for many hundreds and thousands of years. We know that the lakes of temperate regions have, in general, been formed as the result of ice action during the last period of glaciation, some twenty to thirty thousand years ago. It follows that the vegetable materials occupying a completely or

even a partially filled lake are often of great age, in terms of the human chronology. The lowest depths, for example, may contain remains thousands of years old. These are nevertheless in a perfect

FIG. 6.—Section of a leaf of a waterlily from six feet below the surface of a filled lake, Cambridge, Mass.

condition of preservation, if the lake during all the intervening centuries has remained filled with water. It follows from the conditions described above that an accumulation of vegetable materials ten feet or more in depth, within the area of a lake, has been

a long time in formation, and that, other things being equal, age will correspond to depth. The accompanying photograph shows a section of a leaf of a waterlily, taken by means of a probe from a level six feet below the surface of a filled up lake, within the boundaries of Cambridge, Massachusetts. The condition of preservation is remarkable, in view of the probability that the interval which has elapsed since the leaf belonged to a living plant, may be measured in thousands of years. The whole deposit in this instance was ten feet deep and was probably accumulated in the course of from fifteen to twenty thousand years.

The remains of fabrics, fruits, utensils, and even boats of the Neolithic Lake-dwellers of Europe, are often found in a good state of preservation. Their condition in fact is often such that it has been possible to form detailed and exact opinions in regard to the habits, industries, foods and even the cultivated plants of the Lake-dwellers. Deposits of later and historic times, of the Roman and subsequent periods, under similar conditions of water cover, have supplied data as to the rapidity of the accumulation of peat. An interesting case of this kind is reported by Renault (*Microörganismes des Combustibles Fossiles,* St. Etienne, 1900). A body, with well preserved garments belonging to the eighth century, was found at the depth of ten feet in a bog in Friesland. In this case, supposing that the body had not sunk any by its own weight in the soft

muck, the rate of deposition was one foot in one hundred years or one hundredth of a foot in a year. This is probably an excessive rate for accumulations in water, but on this basis, our leaf of a waterlily shown above, must at the very least be six hundred years old.

In addition to vegetable materials accumulated under open water, as in the case of lakes, lagoons, estuaries, etc., we find in temperate climates the formation of large terrestrial deposits of so-called peat. This sort of formation is confined to regions nearer the poles. In Europe, for example, it does not extend south of 45 degrees of latitude, except on the mountains. In America, the limit for the formation of peat extends somewhat further south. Peat is formed only where the temperature is such that the sun has not a high evaporating power. Under these conditions, vegetable matter can remain constantly wet, even when its level is considerably above the water of the soil. Such accumulations contain little or no mineral matter, as they owe their moisture almost entirely to atmospheric water and not to that of the soil (telluric water). In the United States as a whole, according to the investigations of the late Dr. C. A. Davis (*The Origin of Coal,* Bulletin 38, United States' Bureau of Mines) a relatively insignificant amount of peat is formed above the normal level of the soil-water. Investigations carried on by Professor C. C. Forsaith in Florida (*Botanical Gazette,* Vol. 62, pps. 32-52, *Idem,* 63,

pps. 190-208), are strikingly indicative of the necessity of a constant water level for the formation of vegetable accumulations in warm climates. In the tropics, where the heat of the sun is very efficient in causing evaporation and the action of wood destroying organisms is intense, no real peat bogs have yet been found, despite statements to the contrary.

It is customary to distinguish those accumulations of vegetable material, which are formed above the level of the soil-water as high-bogs (Hochmoore), while those in which the formation is mainly a sedimentation under open water, are known as low-bogs (Niedermoore). There are important differences between the two. The latter category of deposits occur both in warm and temperate climates, while the former are strictly confined to relatively high latitudes. The structural conditions in the two are also strikingly different. In the case of lacustrine mucks, whether fine or coarse, pollen grains and spores are usually conspicuous as well as the remains of water-plants and water-animals. Further, their components are in a good condition of preservation. In the case of the peat of the high bogs of high latitudes, pollen grains and spores are conspicuously absent and also the remains of water-plants. The condition of preservation, particularly in the deeper layers, is bad, and the color of the material is dark, in contrast to the lighter hue of aqueous deposits. The accompanying photograph shows a section of commercial peat from Cambridge, England. The

decayed condition and the absence of spores are outstanding features of this sort of accumulation. In Europe, peat is used as a source of heat, although its calorific power is only a third to a half of that of good coal, and it produces a smoky and incon-

FIG. 7.—Section of ripe or mature peat, Cambridge, England.

stant fire. Peat was formerly dug for domestic use on the coastal islands of New England, but has in modern times been completely replaced by coal. The rising price of the latter fuel, however, is likely in time to revive the use of peat, whether accumulated in lakes or bogs.

CHAPTER V

FIRE AS A PRESERVATIVE

It has long been known that fire has a preservative action on wood. This agency is often invoked in the case of wood set in the ground. If the embedded region and the portion just above it, are exposed to superficial charring, the life of the structure is much prolonged. Charcoal is practically imperishable except as the result of combustion. Charcoals of the remotest geological ages reveal wood in a superb condition of preservation which is not approached by that found in the best petrified or mineralized material. In the so-called drifts of South Africa, charcoal pebbles from the Mesozoic period, which have obviously been much rolled in water, are abundant. In coal itself, which will be discussed in detail in the pages following, charcoal is a common constituent. Charred remains too are a fruitful source of archæological information. From material in this condition it has been possible to learn much in regard to the foods of the Lake-dwellers, the Romans, and the ancient Scandinavians. In the preceding chapter the value of water as a preservative has been discussed. Water communicates, however, no qual-

ity of permanence to the materials which it safeguards from decay. If they are later exposed to air and the action of destroying organisms, they fall

FIG. 8.—Magnified views of opposite ends of a partly charred twig, from the Cretaceous, of Staten Island.

a prey to disintegration. Indeed the secular action of water itself on wood is destructive, as we know to be true in the case of many woods in the lignitic conditions. Plant remains which have once been

exposed to the action of fire, are to all intents and purposes imperishable, except by the further action of fire itself.

In the accompanying photograph is shown a tranverse slice of a fossil branch from the Mesozoic of Kreischerville, Staten Island, N. Y. The wood is in a practically perfect condition of preservation, showing the minutest details of structure in spite of the fact that it has lain in the ground possibly twenty millions of years. This state of perfection is the direct result of the fact that it had been scorched in an ancient forest fire. In the lower item of the same figure is shown the other end of the same branch, which had not happened to be exposed to a high charring temperature. The degree of heat had been enough to prevent actual decay, but the structural organization of the branch, so clearly obvious at the opposite end, has largely disappeared. Further, the uncharred end has undergone a great shrinkage in volume. Woods not exposed to heat or mineralization, commonly completely lose their organization ultimately, and undergo a diminution in volume far greater than that shown in the contracted end of the partially charred branch figured here.

Frequently one finds in coals of various ages, remains of charred woods. Figure 9 shows a good example of this condition. It illustrates a vertical section of coal, which for the most part shows very little evidence of structure and in its natural hue

is dark brown. Running horizontally across the substance of the coal is a band of charred wood, in which the cells can be very clearly distinguished. In other cases, where a fragment of wood has been unequally exposed to high temperature, it is often pos-

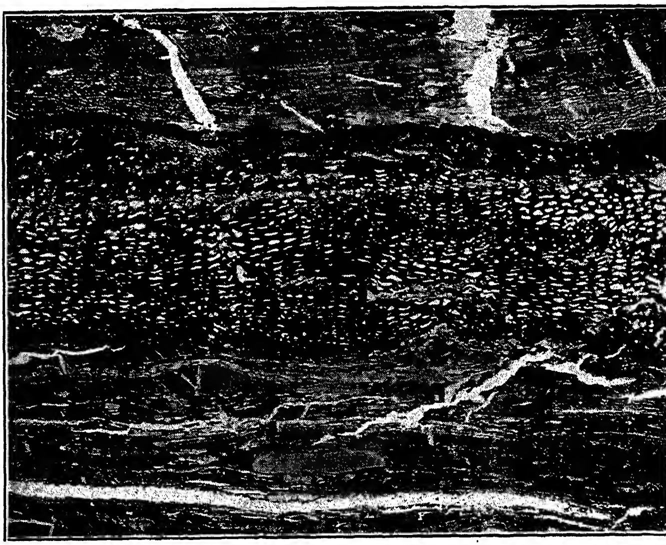

FIG. 9.—Magnified view of a vertical section of a coal from Utah, showing charred wood with structure preserved.

sible to trace the gradual gradation from wood with structure preserved to the entirely structureless material of which coal is frequently largely composed. The fibers of the woods in such cases swell up and finally collapse. The general aspect of a wood passing into the condition of coal is well shown in Pho-

tograph 10, which reproduces a transverse slice of a piece of wood from the Jurassic coal mines of Brora in Scotland. The minuter details can be observed in Photograph 11 illustrating the organization of a partially charred wood from the coal of the Laramie

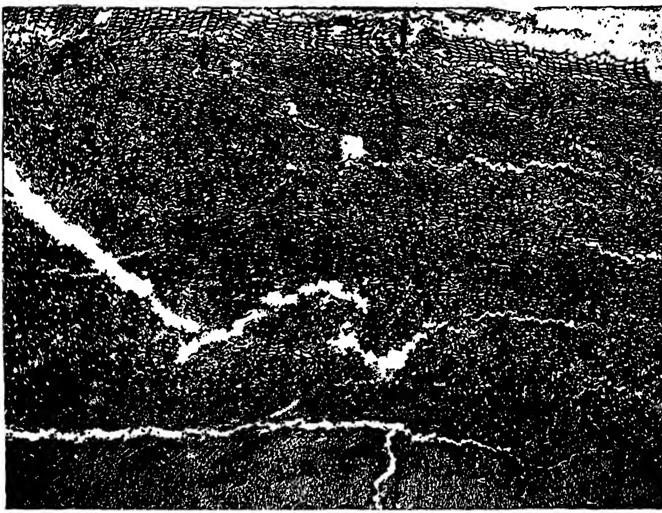

FIG. 10.—Transition from charred wood to structureless coal from Jurassic coal, Brora, Scotland.

or Upper Cretaceous of Montana. The wood is that of an extinct Big Tree or Sequoia in the earliest epoch in which that tree is authentically known to occur. In the upper left of the illustration the fibers are still clearly distinguishable, but their walls are much swollen. Towards the right above they gradually collapse and the cavities disappear. In

the lower region of the figure throughout, the organization of the fibers has practically disappeared.

It is clear that water cover in the long run does not guarantee the preservation of vegetable structures, although it does insure to a large extent at any rate

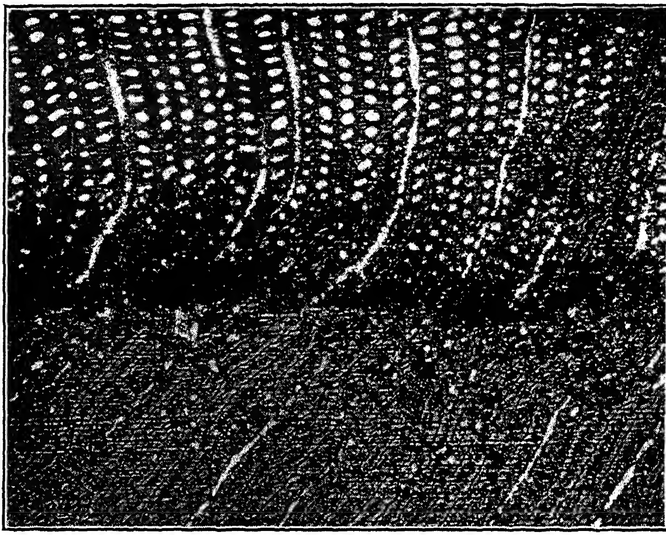

Fig. 11.—Transverse section of partly charred wood from the Cretaceous of Montana.

the preservation of vegetable materials, albeit in a degree of chemical alteration, corresponding in some measure to the age of the coal, but more particularly related to the chemical and physical influences which it has undergone. A very important advantage which coal has over wood is its heating

power. Ordinary wood is composed mainly of carbon but also very largely of hydrogen and oxygen. In coal the oxygen has more or less completely disappeared, depending on whether the coal is of highest grade such as anthracite, or of the lowest, as for example brown coal. This loss of oxygen is brought about in some way, which has not as yet been satisfactorily elucidated. Possibly the long sojourn of the raw materials of coal under water, and subject to water action, has brought about a chemical modification, which permits the oxygen to pass off or enter into other combinations in such a manner as to leave the carbon and most of the hydrogen behind in a concentrated condition and capable of producing a very high degree of temperature in combustion. Since combustion is the combination of oxygen with combustible or burnable material, it follows that the less oxygen the combustible naturally contains, the larger the amount of heat will be evolved in the process of burning.

Another signal advantage which vegetable material in the form of coal possesses over such material in its crude condition, is concentration. Woods of the type which have entered into the composition of coal had a weight which to judge from living trees could not have been more than twenty to thirty pounds to the cubic foot, or from five to eight hundred pounds to the cubic yard. A cubic yard of coal weighs approximately one ton or two thousand pounds, so that the transformation of crude vege-

table material into coal has brought about a concentration of from two and a half to four times in amount of combustible matter. When this advantage is added to the loss of oxygen described above, it is easily seen why coal is the fundamental mineral of our essentially industrial civilization, and capable of developing an unequaled amount of energy.

Coal is the great unoxidized and yet easily oxidizable mineral, and as a consequence it is the all-important source of energy. The only other substances indeed which occur in nature in an unoxidized condition are the precious metals, and these are of no value as sources of energy, with the exception of radium and related elements, which are so rare as to be practically negligible. The enormous amount of coal, or water-cured, time-ripened, and pressure-concentrated vegetable matter, which our earth contains, is another outstanding cause of the fundamental importance of coal in industry and the arts. It is conceivable that we may some day push our chemical knowledge so far that we may be able to draw directly on the energy of the sun as green plants do. Until that time arrives, coal and its products, supplemented in certain favorable cases by water power, will supply the forces necessary for the development and continuance of our civilization.

After having briefly considered the nature of deposits of vegetable matter which are actually being formed and the influence upon these of water, oxygen, high temperature, and finally fire, we are in a

position to proceed to the examination of the organization of coal itself. This literally dark subject has received much needed illumination from improvements in the methods of investigating coal, which have cleared up many matters, in doubt and dispute during more than a century. The whole fundamental subject of coal has in fact now reached a stage where blind surmises can be replaced by real knowledge based on tangible facts.

CHAPTER VI

OIL ROCKS AND PETROLEUM

A VERY typical oil-rock, which yields from forty to fifty gallons a ton, when subjected to dry distillation is Tasmanite, from the island of Tasmania. This coal is very light in color, as is the case with many oil-rocks, and is sometimes known on that account as white coal. As it is a very pure coal so far as its organic constituents are concerned, a special examination of its structure, will throw a good deal of light on the very much disputed question of the organization and origin of oil rocks, oil-shales, bituminous schists, torbanites, bog-heads and other oil-yielding minerals. In figure 12 is shown a magnified view of a section made vertical to the layering in Tasmanite. Two round bodies can be seen, which are the reproductive parts or spores of some unknown extinct plant. In addition to these are a number of flattened structures, which represent similar bodies in a collapsed condition. It is only rarely that spores escape flattening where they occur in coal deposits. The more numerous exceptions in the case of Tasmanite are beyond question due to the fact that this coal is largely mineralized,

and accordingly the spores, when they came to rest in a round condition, have preserved their rotundity in spite of the great pressure to which the bed was later subjected by the overlying strata. Probably most of the exceptionally large spores constituting

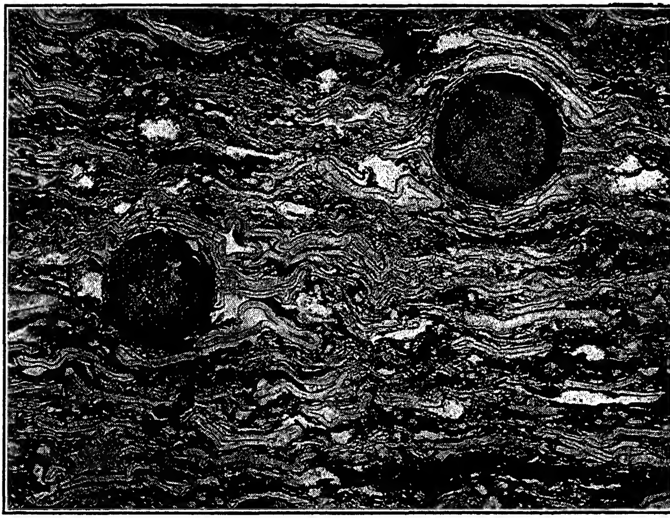

FIG. 12.—Vertical section of an oil-rock, Tasmanite, from Tasmania, showing a number of flattened spores and two which are still round.

Tasmanite were already empty and collapsed when they reached the bottom of the water, in which they found their original resting place.

In the next figure is shown a horizontal view of a number of spores of Tasmanite as they appear in a photograph under lower magnification. They are

here exhibited as numerous round flat structures, more or less wrinkled on their upper and lower surfaces. There can be no question that Tasmanite is a coal made up almost entirely of spores and that the presence of these bodies endows it with the property of yielding oil when subjected to dry dis-

FIG. 13.—Horizontal view of Tasmanite.

tillation. In general spores have a high content of oily and resinous substances, or hydrocarbons, and their yield of oil in a fossil condition is accordingly not surprising.

It is impossible to go further into the subject of the origin of oil-rocks without giving some consideration to the organization of the spores in certain

lower fernlike plants. The accompanying photograph shows a number of the spores of the common Ground-pine or Club-moss (Lycopodium) under high magnification. These have a very rough surface particularly when what is known as the posterior surface is presented to view. A number of the spores show a curious triple radiating marking of the surface. When this feature is seen, the anterior aspect of the spore faces the observer. This marking is due to the fact that the spores of the Club-mosses and their allies are formed in fours and the tetrad sticks together until a late stage of development of the spores. As a consequence each anterior or contact surface of each spore shows the imprint of the three sister spores of the tetrad. In the case of spores and pollen grains which are differently arranged in the tetrads or which separate from their sisters at an earlier stage of development, the triradiate marking of the anterior face is not seen. For example, although the pollen grains of Conifers, deciduous trees, grasses, etc., are likewise formed in fours, they never show any indication of the peculiar three-armed marking found in Club-mosses and their allies.

Another interesting feature of the spores of the common Club-mosses as well as of other spores is their high content of hydrocarbons or fatty substances. In the spores of Lycopodium the fatty or oily material often makes up fifty per cent, or half of the grains. As a consequence of this property,

they serve admirably for coating sticky pills and preventing their adherence with one another, and are in fact universally used by pharmacists for this purpose. Another and even more significant feature in the present connection, is the high degree of in-

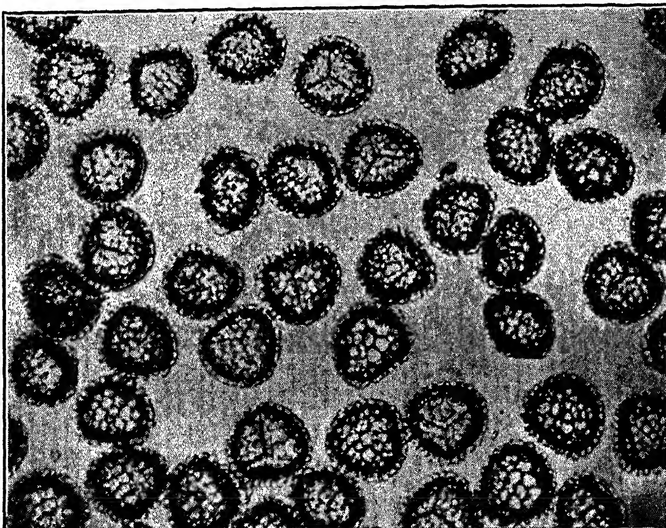

FIG. 14.—Highly magnified view of the spores of the club moss, Lycopodium.

flammability of the spores of Club-moss. When thrown on the flame of a match or candle, they produce a blinding flash of light. On account of this property they were used in Elizabethan and later times for producing an imitation of lightning on the stage. Electricity has now replaced the spores of Lycopodium for such purposes. Spores, how-

ever, as I have been informed by one of my students, are still used in the theatrical performances of country villages in Japan.

We may now turn our attention to the structure of American and other oil-yielding rocks, the compo-

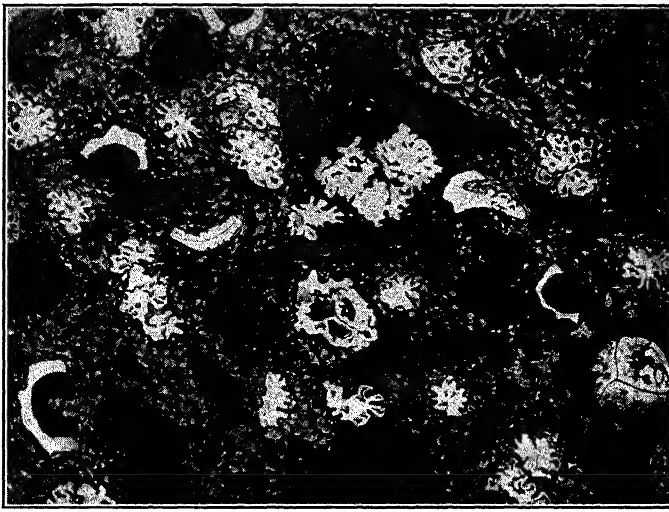

FIG. 15.—Horizontal view of an oil shale from Kentucky.

sition of which has been a matter of dispute, by reason of the inadequate methods used in their investigation. Figure 15, reproduces, highly magnified, the structure of a section horizontal to the surface of oil-rock from Kentucky, which goes under the curious name of bog-head coal. A number of rough-surfaced bodies which are light in color can be seen scattered over the field of view. These ob-

jects have been called *Pila kentuckiana,* by a European investigator and have been considered to belong to a lowly group of water plants known as Algae. A serious difficulty in the case of that interpretation, is the fact that in America at any rate, no Algae which have not a mineralized covering, such as the Stoneworts and Diatoms, mentioned in an earlier chapter (page 17), have ever been found in accumulations of vegetable matter in water. A decisive objection however to this interpretation of the organism found in the case of the coal from Kentucky, under discussion, is furnished by the fact that they are clearly spores of lower land plants related probably to the Club-mosses described above. In the center of the figure can be seen a spore with the characteristic three-armed marking, and near it above is an actual spore cluster still intact.

In the next illustration is presented a highly magnified photographic view of the spore and the spore cluster from the center of the figure above, making it clear that they cannot be Algae. In the preceding figure is shown another serious objection to the algal interpretation of the bodies under consideration. A number of more or less irregular darker-hued objects are scattered through the section. These represent fragments of wood, which have entirely lost their structure. It is not reasonable to suppose that delicate organisms like Algae, consisting often of 98 per cent. or more of water, should have maintained their structure under conditions which have

completely destroyed the organization of a comparatively resistent material like wood. We must accordingly interpret *Pila kentuckiana* as the spores of an extinct land-plant which have come to rest in water, and not as the bodies of delicate Algae. The author has shown that similar organisms occur-

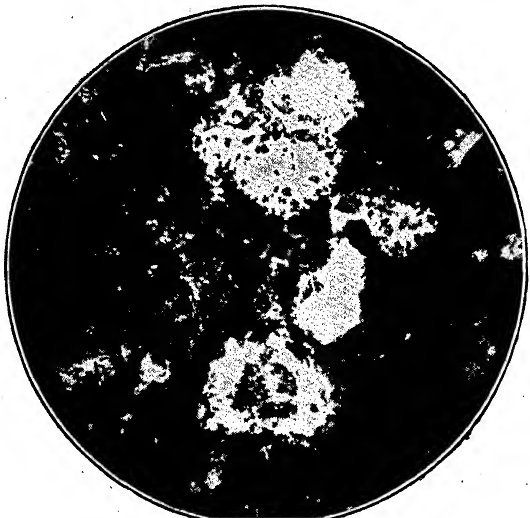

FIG. 16.—Highly magnified view of the spores shown in Fig. 15.

ring in European coals are likewise spores, and it is accordingly practically certain that all organisms which from their structure have been referred by various investigators to the genus *Pila,* are likewise spores and not Algae. The spores and the structures representing the modified wood, are found imbedded in a darker matrix in the two figures shown herewith.

The origin of the matrix is revealed by a comparison with the condition in the bottom muck of our existing lakes. Here we find spores and small fragments of wood laid down in a gelatinous matrix derived in all probability from the ejecta of aquatic animals and possibly also from the slime of mucilage of water plants. The probability of this view is much strengthened by the fact that we frequently find the mucilaginous substances in petrified plants actually presenting the same black or very dark hue, which characterizes the matrix of oil-rocks and other similar coals.

It may be reasonably assumed from the facts stated above, that so far as bogheads containing *Pila* are concerned, we have to do with fossilized spore deposits accumulated in open water. In other cases, however, it is not possible to identify the spores conclusively by the presence of triradial markings. This is particularly the case when the bodies in question are of large size and closely massed in the oil-rock. The next illustration reproduces the organization of an oil-rock or boghead from Scotland known as Torbanite. This has the distinction of being the earliest oil-rock mined and distilled for oil. In France and Australia similar deposits are mined and exploited by distillation. There are likewise huge deposits, in some cases amounting to whole mountain ranges, of like materials in North America. They are not however likely to be mined and distilled for oil at the present time, as the supply

of natural oil in the United States and Mexico is still too large to justify the distillation of even these abundant oil-rocks for their highly useful products. It is said that only when crude petroleum reaches the price of at least five dollars a barrel, will it be-

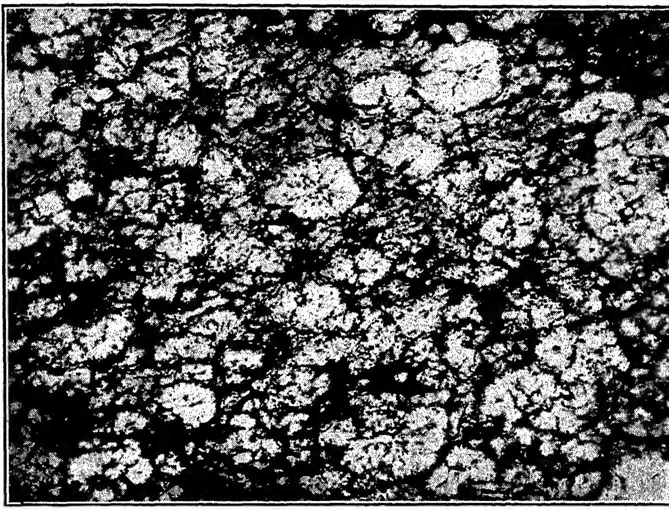

FIG. 17.—Horizontal view of Torbanite, an oil shale from Scotland.

come commercially profitable to distill the plentiful oil-rocks of Colorado and other western states.

It is convenient at this point to discuss briefly the theory of the derivation of oil from fossil Algae. It has been made clear above that when the bodies supposed to be Algae belong to the genus *Pila,* they are obviously spores of land plants. In the case of the other similar organisms, abundant in many oil-rocks,

the structure is not so conclusive, in the absence of the triradiate marking, which supplies a definite identification of spores. This is however not a serious difficulty because in the unquestionable spores of Tasmanite, an Australian oil-rock, this feature is likewise absent, as is also universally the case with the spores or pollen of all known seed-bearing plants. Although the oil-shales of certain regions do not produce spores with the characteristic markings of the Club-mosses, they are none the less true spores. They show the same superior resistance to the destroying agencies of time, heat, and pressure, in contrast to the accompanying woody structures, which unless charred before deposition, generally lose all recognizable organization. A very serious difficulty presented by the algal hypothesis of the origin of oil-rocks is the relatively small amount of hydrocarbons or oily substances, present in Algae in contrast to the abundance found in spores, namely not more than three to four per cent in the former, and often fifty per cent in the latter. Further, the amount of bituminous matter found in oil-shales, etc., is much in excess of what they could theoretically produce, supposing their constituent organisms to be Algae. It is suggested by those who hold the algal hypothesis of the origin of oil-rocks, that the bituminous matter has come from elsewhere and has infiltrated the supposed Algae. Bituminous matter is insoluble in water, and yet the bodies of Algae usually contain 98 per cent or more of water. The

only manner in which the entry of bituminous hydrocarbons into Algae can be imagined, is as a result of the previous drying out or desiccation of the algal structures. This would have involved a degree of shrinkage which is not observed in the case of the organisms found in oil-rocks. Further it is impossible to conceive of deposits of such perishable material as Algae accumulating to the considerable depth found in the case of many deposits of oil-shale. It is still more impossible to imagine how all this material could have been dried out under water cover and subsequently become infiltrated with bituminous matter. The origin of the bituminous matter itself is also a very serious difficulty because there is no obvious external source for it. In the case of the mummies of the Egyptians, the corpses of the higher classes were preserved by bituminous antisepsis, but the bodies, to judge from autopsies, which have been made on them by competent anatomists, were first dried by extreme heat, often so great as to destroy the hair on the surface. Even under these very favorable conditions, the preservative penetrated very slightly, and frequently as a result the mummies disintegrate when brought into a damp climate. The algal hypothesis of the origin of coals is thus beset with insuperable difficulties and it appears moreover to be a superfluous hypothesis based on erroneous data.

Whatever differences of opinion may have existed as to the nature of the organisms found abundantly

in oil-rocks, oil-shales, bituminous schists, bogheads, etc., there is no dispute as regards their being the source of petroleum. Except under unusual conditions, the distillation of oil-rocks for production of oil, is as yet not commercially advantageous. There is little doubt however that we shall sooner or later be compelled to resort to this source of supply. The end seems in sight in the matter of the supplies of naturally distilled petroleum, which are the product of the action of the internal heat and pressure of our earth, on oil-bearing rocks. It accordingly appears highly inexpedient for any nation, however powerful, to pursue a policy of aggression, in the interests of a monopoly or domination of the supply of natural oil. The gain will be of too short duration to be worth the enmity thus incurred. However advantageous the winning of natural oil may prove to individuals and groups of individuals, it can not be regarded as a safe field for national enterprise.

When our very limited supplies of natural oil are exhausted, and we are compelled to have recourse to the distillation of oil-rocks, the cost of petroleum and its products will be much increased. Gasoline will doubtless in the long run be replaced by some other volatile fuel suitable to the needs of the internal combustion engine, which figures to an ever increasing degree in the activities of our present civilization. It can not be too strongly emphasized that petroleum is the quintessence or extract of certain special types of coal, which are extraordinarily rich in the spores

or reproductive parts of long extinct plants. It is impossible to expect that in the long run we can keep going on the naturally distilled quintessence of our coal deposits. The skill of our chemists and engineers will probably however solve the problem of convenient and economical substitutes for petroleum and gasoline.

CHAPTER VII

CANNEL COAL

THIS type of coal is distinguished by its high product of illuminating gas when burned, resulting in unusually long and vivid flames. The name is derived from this peculiarity and is a Scottish dialectical variation of the word candle. The French either adopt the Scotch word or refer to it as *charbon à longue flamme.* Another North British appellation for certain forms of this coal is parrot coal. This comes from the crackling noise produced by certain cannels while undergoing combustion. Cannel coal differs from most oil-shales by its black color. It further presents a contrast to ordinary bituminous coal by its dull waxy lustre and its less definite cleavage. This type of coal is valuable in the manufacture of illuminating gas and likewise provides an attractive and cheerful fuel for the fireplace, which satisfactorily replaces the vanishing wood fire of our forefathers.

Cannel coal is closely related to oil-rocks and often it is difficult or impossible to distinguish them apart. Like oil-rock, its components were laid down in tranquil water and consisted to a predominating

degree of spores. Associated with the spores however in this type of coal, we find a large amount of grosser vegetable material. In the process of transformation of such deposits into cannel, the less refined constituents undergo profound changes, involving in most instances a complete loss of structure. The spores appearing golden in color, are almost as imperishable as the yellow metal itself. They show in section as flattened bodies with a central cavity almost obliterated by pressure. In addition to the spores and more crude vegetable materials, which become structureless in the fully formed coal, there is present in cannels a darker fundamental matrix, more or less abundant. This dark ground substance, from the study of existing lacustrine deposits resembling cannels and oil-shales, is inferred to represent the more perishable parts of plants and the ejecta of aquatic animals.

Figure 18, represents a view of cannel coal from Kentucky, rather more highly magnified than that of Tasmanite on page 45. It is obviously very much finer in structure than the oil-rock. The spores are minute and appear as small light horizontal stripes. Intermingled with these are less regular structures which unlike the spores are without structure. These were originally small fragments of wood and other more durable débris, which sank to the bottom at the same time as the spores. Below the middle of the picture is seen a large mass of structureless material which once was wood. The two kinds of objects just

described stand out on a darker background derived from the more perishable materials, which sank to the bottom of the coal-lake, namely the ejecta of aquatic animals and the mucilaginous products of plants.

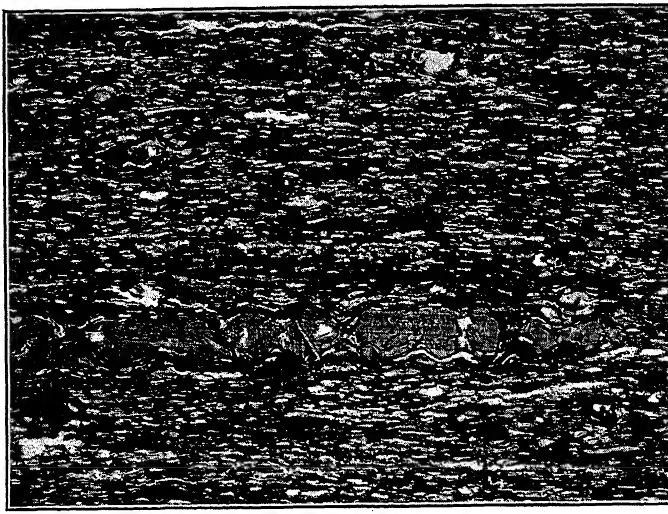

Fig. 18.—Vertical view of cannel coal from Kentucky, magnified about 200.

The next figure illustrates a very highly magnified vertical slice of cannel. The spores are now sufficiently enlarged to be clearly seen and it is obvious that they are all flattened horizontally. Intermingled with the spores are darker hued, less regular bodies, which represent fragments of wood and similar material, which have entirely lost their structure.

The darker matrix also stands out much more distinctly in the enlarged view.

The illustration on page 62 represents the same coal in horizontal section, very highly magnified. The flattened spores are now visible in face view and

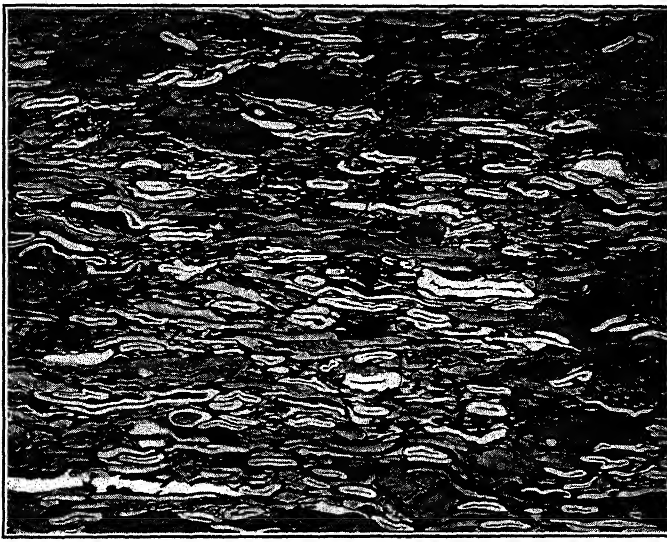

FIG. 19.—Vertical view of cannel coal from Kentucky, multiplied by 500.

on some of them can be made out the three-armed marking indicating their original association with three other sister spores in a tetrad. The irregular darker objects represent fragments of wood which have lost their structure in the process of transformation into coal. In the center a tiny fragment of

wood consisting of portions of two fibers has retained its organization as a consequence of blackening and charring by fire, in some ancient burning of the forest. The dark fundamental substance shows more variety than in the vertical section.

By comparing the illustrations and descriptions of

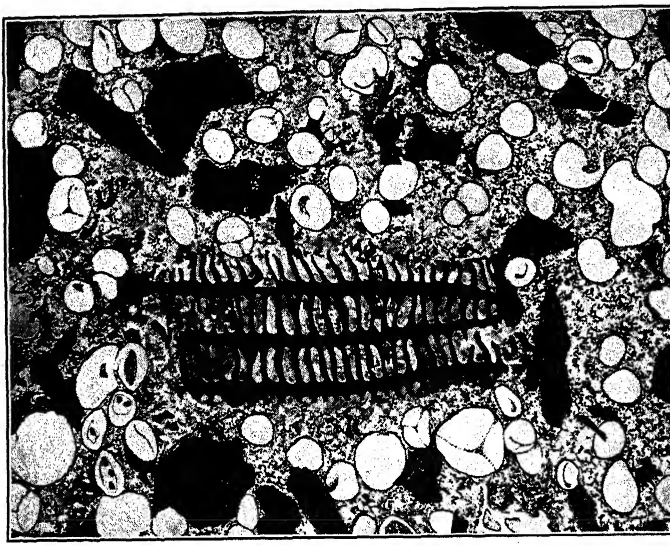

FIG. 20.—Horizontal view of cannel coal from Kentucky, multiplied by 500.

cannels and oil-rocks, it will be clear to the reader that the latter are on the whole a purer product than the former. They are made up moreover of materials which darken less with age, chemical action, and pressure, than do cannels. Otherwise the differences between them are not great and many cannels

as a matter of fact serve for the distillation of oil in countries where natural oil is not available. Both cannels and oil-rocks are deposits of tranquil and often deep waters. They further must be considered as representing the élite or aristocracy of coals as their occurrence is relatively scanty compared with the bituminous coals and similar combustibles. The dry distillation of oil-shales and cannels will consequently never supply, even at a much enhanced price, sufficiently copious substitutes for our natural petroleum.

CHAPTER VIII

BITUMINOUS COAL—PEAT COALS

IT has been assumed by the majority of geologists that coals of this category are derived from ordinary peat. Numerous more or less forcible and convincing arguments have from time to time been advanced in favor of this view and to emphasize the supposed different origins of coals of the bituminous category from the cannels and oil-shales; they have in more recent years been designated humic coals, in view of their supposed origin on land. Another phrase which has a similar implication, is the expression "formation *in situ.*" The terrestrial or *in situ* hypothesis of accumulation of the raw materials of coal has its home in northern Europe, where wide and conspicuous expanses of vegetable accumulations of the high bog type described in Chapter IV, afford a strong visual suggestion for such a theory. The German noble, von Beroldungen, appears to have been its first exponent over a hundred years ago, and its ablest and most convincing advocates have been largely Germans. In opposition to this view of the origin of coal, is the one which has many advocates in France, namely that bituminous coals, like can-

nels and oilshales, have been accumulated in open water and as the result for the most part of transport by wind and water.

It would be going beyond the limits of this modest volume and also exceeding the necessities of the case, in view of the present condition of our knowledge, to discuss these theories at any great length, particularly as they have been based for the most part on an almost complete ignorance of the all-important internal structure of coal. It is only now that the actual organization of all important types of coals is available in the discussion of the origin of this invaluable mineral. The results from the standpoint of structure are apparently so clear and convincing as to set at rest further controversy.

It will accordingly be more profitable to begin with the actual organization of coals of the bituminous category, rather than to attempt to discuss the huge quantity of writings on the subject, which so far as the essential features of intimate structures of coal are concerned, almost entirely lack basis in facts. The strongest argument for the peat or *in situ* formation of coal is furnished by the so-called coal-balls of certain of the European coal-fields. These are abundant in parts of the Lancashire and Yorkshire coal-fields in Great Britain. They are also found in the Westphalian coals in Germany, in the great Donetz region of Russia, and likewise in Austria. Very recently a few structures of this kind have been described for the United States, but these have not

as yet been sufficiently studied to warrant any conclusions of a general nature. Since our knowledge of the internal organization of extinct plants has depended, until comparatively recently, entirely on materials of plants in a condition of mineralization or petrification, the occurrence of petrified portions of coal has been naturally welcomed as clearing up the prolonged controversy in regard to the origin of this all-important combustible. The development of methods for the investigation of the much more abundant carbonized and carbonified remains found in coal, however, make it clear that the evidence based on the structure of the relatively rare petrifactions known as coal-balls has only a limited bearing on the large and important problem of the origin of coal.

Figure 21, is a photographic reproduction of a part of a slice made by means of the grinding lathe of the mineralogist, through a coal-ball from Lancashire, England. Obviously the materials present are in a remarkable condition of preservation; particularly is this true of the woody parts. The illustration is to be compared with Figure 4, on page 24, which represents an accumulation of plant materials in the open water of a small lake.

The state of preservation of the structures in the illustration is such that there is a strong indication of transported material, laid down in and preserved by a constant or rising level of open water. There are no indications of attack by micro-organisms and

consequent disintegration, such as shown in figure 7, page 34 which represents ordinary ripened peat from below the surface of a bog. Figure 22 shows the structure of the actual coal from the same coal-bed in Lancashire. The substance is traversed by

FIG. 21.—Section of a coal ball from Lancashire, England.

many cracks and fissures but beyond these, shows little evidence of structure. It has every appearance in fact of woody matter, which has lost its organization as a result of secular water-action and pressure. Examples of changes of this kind are described in an earlier chapter. (Chap. 5, pages 39 and 40.) The organization of the coal in a seam containing

coal-balls from the Westphalian coal field is shown in the illustration on page 69. Here the substance of the coal has undergone less cracking and a further difference is observable in the fact that the structure of the coal is not homogeneous. This lack of uni-

FIG. 22.—Section of the coal from the same seam which contains the coal balls.

formity is due to the presence of veins of a darker matrix, apparently derived from material of a more perishable nature than wood, in other words comparable to the dark matrix of cannels and oil-shales. The Westphalian coal under discussion was actually broken off the surface of a coal-ball kindly sent to the author by the Geologische Landesanstalt of

Prussia just before the recent war. There is accordingly no reasonable doubt that it represents the modification into coal of material similar to that found in a preserved and petrified condition in the coal-ball, from the surface of which the coal in this

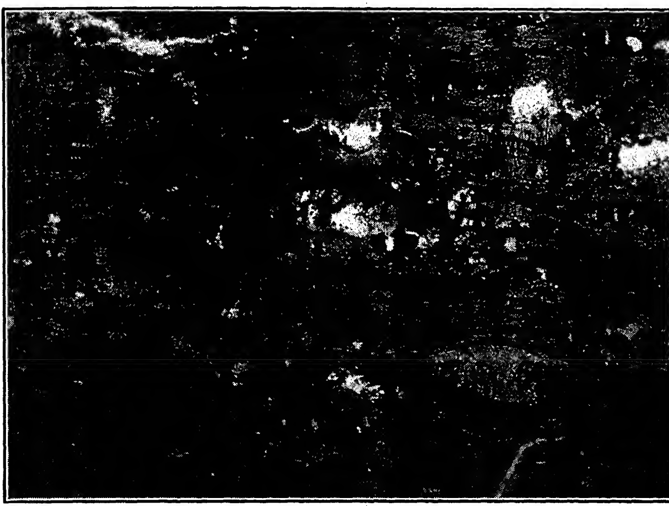

FIG. 23.—Section of coal from a seam containing coal balls from Westphalia, in Germany.

instance was actually taken. The examination of coal surrounding a coal-ball from the Donetz field in Russia, generously supplied by the Comité Géologique of Petrograd, before the war, reveals a similar condition of organization. On the facts supplied by coal-balls and their surrounding coal, *alone*, it consequently is possible to argue for the correctness

of the hypothesis of the derivation of coal from ordinary peat.

Unfortunately for the general soundness of such a conclusion, however, the coals containing coal-balls are not normal coals. They have been recognized as belonging to maritime or so-called paralic bogs, and thus present a contrast to most coals, which obviously are the result of fresh water conditions of deposition. The coal-balls of England moreover, do not even reveal material, which was necessarily formed *in situ*, for scattered through their substance are isolated fragments of charred wood, which are naturally explained as remains, from time to time swept into the waters after recurring conflagrations in the surrounding forests. That this is the rational elucidation of the presence of the charred structures in the coal-balls of Lancashire, is made clear by the observation of the materials accumulated in the layers of lake deposits in the present epoch. These often show charred twigs and other remains embedded irregularly throughout. If the material in the coal-balls had been deposited *in situ*, the advent of fire in a dry season would have caused a general charring, such as is conspicuous by its absence both in the coal-balls of Lancashire and the present accumulations in open lakes.

Another serious difficulty is presented by the higher and more uniform temperatures, which in general prevailed in earlier geological epochs. The advocates of the peat bog hypotheses of the origin of

coal have attempted to minimize the importance or even the existence of warm climatic conditions during the coal periods. Both the character of the plants however, and the uniformity of structure of their woods, which are without the strongly marked annual rings, of modern plants in higher latitudes, vouch for a much warmer and more equable annual temperature, than that which now prevails in the temperate regions, where coal deposits are abundant.

It is a well known fact that true peat bogs can only flourish in climates where the atmosphere is cool and the evaporating power of the sun is small. In Europe they are stated by Renault not to extend south of latitude 45, except on the mountains. It is accordingly entirely improbable that real peat bogs existed in the earlier and copious periods of coal formation, since they are not found in tropical and subtropical regions at the present time.

It is often erroneously stated that true peat bogs are found in tropical and subtropical regions. The investigations of Forsaith on the peat deposits of Florida (cited above) strongly negative this assertion, so far as the warmest part of the States of the eastern seaboard is concerned. He found in the case of apparently large deposits of true peat, that the aërial or *in situ* portion was confined to a very thin layer on the top. The material beneath in all the cases examined by him was aquatic in its origin, as revealed both by the nature of the deposit and the numerous indubitably aquatic remains

which it contained. Another much emphasized and quoted statement in regard to the occurrence of true peat deposits in the tropics, is that of Potonié (*Die Rezenten Kaustobiolithe und ihre Lagerstaetten*, Berlin, 1910-12, three vols.) based on the data supplied by Koorders in Sumatra. Here an extensive boggy region covered with forest is described. The substratum, on which the trees were growing, is asserted however by this author to contain large quantities of spores and pollen. It is accordingly clear from the description supplied in an earlier chapter, of the mode of filling of a lake, that the trees of this Sumatran bog were growing over the surface of a filled lake, part of which indeed according to the description quoted by Potonié himself, was still open water. The preservative action of constant water cover on vegetable remains has already been emphasized, and this condition is as well illustrated in tropical regions as in temperate. It may accordingly be stated that assertions in regard to the presence of true peat bogs in tropical and subtropical regions are without real foundation in fact, since by far the greater amount of the deposits in question, is aquatic muck and not terrestrial peat. They are moreover laid down for the most part by wind and water and under constant water cover. In other words, the statements regarding the occurrence of true peat in warm countries are based on a confused conception of the nature of peat as contrasted with lacustrine or estuarial muck. The materials

of the bogs of northern Europe, as well as of the tundras of northern Canada and Siberia, are laid down in an entirely different manner from those deposited in lakes and other bodies of water. Their constituents are also different and the chemical action which more or less rapidly modifies the organization of true peat is almost exclusively biochemical, that is, brought about through the activities of lower living organisms. In the case of lacustrine muck on the other hand, the only destructive agencies which normally produce essential changes are water animals and the slow prolonged action of water itself, which requires centuries and even ages, to effect marked results.

A very common error, is that the modification which in the course of time brings deposits of crude vegetable materials into the condition of coal, is in the main, the result of the action of the lower organisms. This erroneous idea results from the observation of the fate of dead vegetable materials as they lie at or on the surface of the ground. Such remains of plants fall more or less rapidly prey to wood-destroying fungi, unless they contain natural antiseptics, as is the case with the darker hued and extremely durable heart-wood of many forest trees. The older American wooden houses owe their survival to the fact that they were built only of the antiseptic heart-wood of the huge secular primeval trees. At the present time we must perforce use comparatively slender trunks, which for the most

part are second or even third growth on the lands. It is thus impracticable to eliminate the highly perishable sap-wood from the narrow lumber, and the duration of our modern wooden houses is correspondingly shortened. All vegetable remains, not charred by fire, or covered by water, disappear sooner or later under the action of wood-destroying organisms. Ideas based on this course of events are often erroneously transferred to the problem of the formation of coal. For example there is an ingenious view in regard to the origin of the seemingly charred fragments of wood, which are very common in many coals. It is asserted that these are the vestiges of wood which has been affected by dry rot. This disease is the result of the activity of a definite organism, *Merulius lacrimans,* which permeates the structure of the wood, digests it and finally reduces it to a valueless condition. In an examination of a dry-rotted piece of wood, the destroying organism can always be clearly distinguished and its presence is an unfailing condition of the malady. The author has examined hundreds of samples of the supposedly dry-rotted wood in coals, and only in the very rarest instances has any indication whatever of an organism been found. The real explanation of the presence of material of wood in a more or less altered condition in coal, is conflagrations in the forests surrounding the coal lakes or lagoons. The charred relics, as is often the case in the forest fires of today, were washed by rains or streams into the nearest

body of water and were mingled with other accumulations gathered there.

To understand the formation of coal we should always bear in mind the fact that a continuous immersion in water indefinitely guarantees wood from the attacks of the abundant and active organisms which bring it to ultimate destruction on land, particularly if it be in contact with the soil. It cannot be too strongly emphasized, that under warm or even only mild climatic conditions, the only manner in which the integrity of plant accumulations can be indefinitely secured, is by constant water cover. This fact is so generally recognized in engineering practice that it is surprising it is lost sight of in theories in regard to the origin of coal. The explanation is doubtless the fact, that until the beginning of the twentieth century coal was structurally practically an unknown mineral and views in regard to it were as a consequence based on extremely slight foundations.

Although wood, from the standpoint of human architectural and engineering necessities is indefinitely preserved from destruction by constant immersion, nevertheless in the longer intervals, which are beyond direct human and historical purview, it does suffer change although not destruction. The warm waters of the lower Mississippi are in fact able to effect a considerable amount of solvent action on woods, even within measurable time. Such action is known as hydrolytic. If we combine hydrol-

osis, with elevated temperature and extreme pressure, we find very marked changes taking place in vegetable materials. From the nature of their causes these cannot be considered in any way biochemical, that is due to the destructive action of lower organisms. The investigations and observations of Petzolt (*Beitrag zur Kenntniss der Steinkohlenbildung,* Leipzig, 1882), which apparently have not by any means received the attention their importance merits, are of great importance in this respect. He noted that the lower shod end of piles driven into a strongly resistent substratum, underwent striking changes. The wood became consolidated, with a greater or less loss of structure and a blackening accurately comparable to that of coal. The outer layers most exposed to the influence of pressure, moisture, and the high temperature resulting from driving, became the most coal-like in appearance and properties. In actual experiment with vegetable materials (*Ueber Calamiten und Steinkohlenbildung,* 1841) he found that a prolonged exposure to a high temperature under pressure, also brought about modifications, strongly simulating the appearance of coal. It is thus clear that purely physical and chemical treatment of the raw material of coal leads to the formation of a product, which in its essential characteristics is actually coal.

The hypothesis that coal is primarily due to the activities of micro-organisms upon crude plant materials with temperature, pressure, and hydrolysis, as

merely contributory agencies, is thus open to serious question in view of recent advances in our knowledge of the organization of coals. The structure of coals of all descriptions from all the important coal-forming geological ages, indicates very clearly that their raw materials were in general, originally accumulated in long and even secular time, in open bodies of water. The present conditions governing the fate of such materials seem to make it certain that micro-organisms had little or nothing to do with changes in their substance and composition. This of course does not preclude the presence of micro-organisms in the original materials of the coal, as these were washed and wafted into the lakes. When they sank in the water, however, the destroying fungi lost any important capacity in the disintegration of vegetable materials. A piece of partially rotten wood for example, when it finds a resting place in a lake or lagoon, ceases to rot further, since the active organism or organisms are killed by the water. With the statement of the general principles, which are involved, it is now possible to proceed to the discussion of what may be properly called normal coals, since both in quantity and importance, they present a very marked contrast to those quite abnormal coals which have yielded the petrified nodules known as coal-balls.

CHAPTER IX

BITUMINOUS COALS

In the preceding chapter the organization of the so-called peat-coals has been discussed. It has been made clear that, if the concretions occurring as coal-balls in these coals, are typical of the vegetable materials from which the coals were derived, their original constituents were originally mainly the vegetative parts of plants, namely, leaves, stems, roots, etc. The structure of the actual coal surrounding the coal-balls, confirms this conclusion, since it has the relatively homogeneous structure and the brown hue of vegetative plant materials, which have completely lost their structure as a result of inherent incapacity to resist the conditions present in coal in the making. In figure 22, has been shown the appearance of a peat-coal from the Upper Foot Seam of Lancashire, England, which has provided a large part of the coal-balls. This seam runs into the Gannister Bed, and with this confluence the coal-balls disappear. I have examined the structure of the coal in the Gannister Bed recently described by Miss Stopes, and find that its organization is that of a normal coal, a condition which

seems to strongly fortify the conclusion earlier expressed, that the seams containing coal-balls represent accumulations in water and not on land. Certainly the coal of the Gannister Bed has all the characteristics of an aqueous or lake muck coal. It

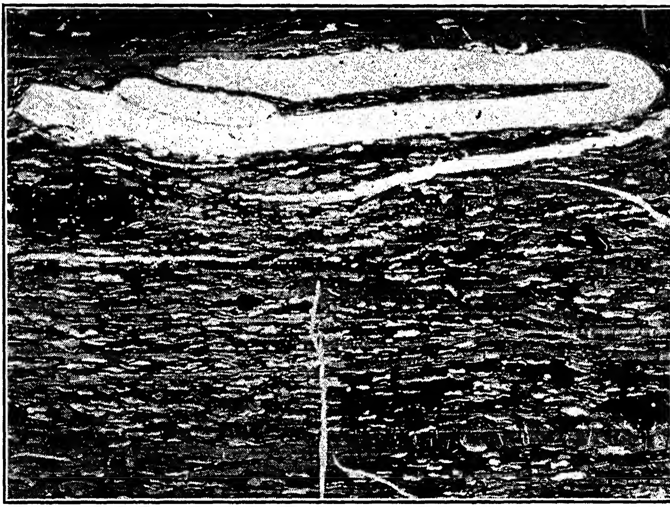

FIG. 24.—Vertical section of bituminous coal from Lancashire, England.

appears unnecessary to introduce an illustration of the Gannister coal in this connection.

In photograph 24, is shown a vertical section of a typical bituminous coal from Haigh Moor, Altofts, Lancashire, England. A large light flattened body appears in the upper region of the photograph. This is a flattened giant spore or megaspore. The

general matrix of the coal is dark hued and corresponds to woody and similar materials which have lost their structure, as is the common fate of all the constituents of coal, except those which have been charred by fire or are of the nature of spores

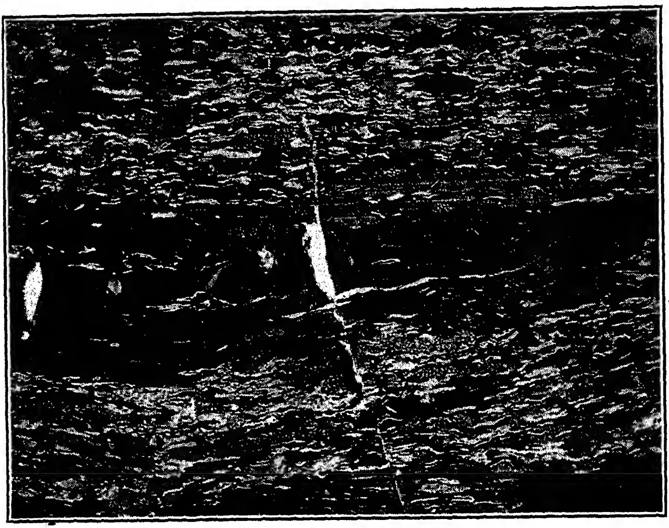

FIG. 25.—Vertical section of bituminous coal from Saxony.

or outer skins (epidermal layers). Scattered through the substance of the coal are innumerable small spores and below the large spore or megaspore on the left is to be seen a small fragment of charred wood, revealed by its black hue.

This coal obviously presents a very marked contrast in structure to the so-called "peat-coals" fig-

ured in the preceding chapter. The very large number of spores present makes it clear that we have to do with a coal laid down under open water, and consequently containing both spores and woody material. The present illustration can advantageously be compared with Figure 22, of the previous chapter.

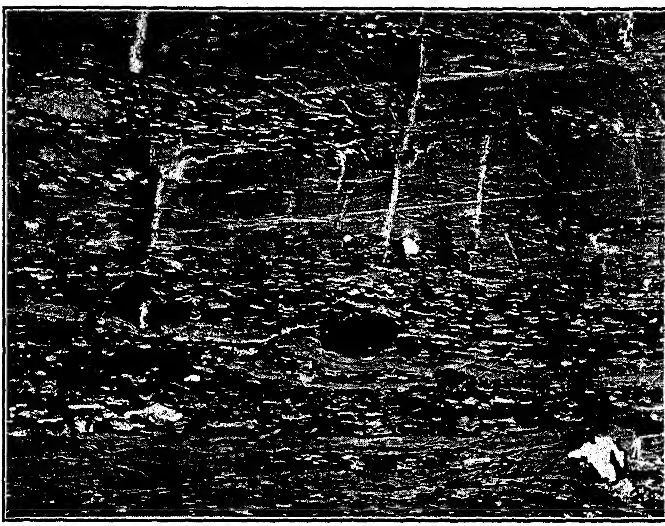

FIG. 26.—Vertical section of bituminous coal from Cape Breton Island, Nova Scotia.

A counterpart to the photograph of Westphalian coal, containing coal-balls, shown in Figure 23, is provided by the next illustration which represents the organization of a black glistening coal from

Zwickau, Saxony. The ground substance of the coal here is of woody derivation. As in the Lancashire coal, numerous compressed spores appear as light bodies scattered throughout the substance. There can be no question as to the correspondence

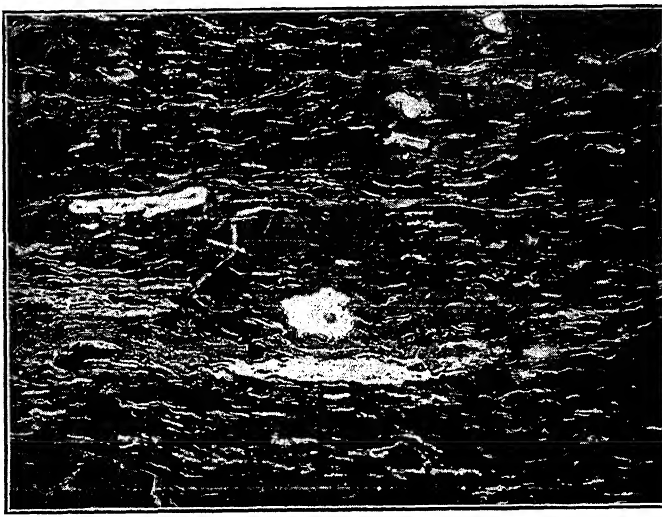

FIG. 27.—Vertical section of bituminous coal from Pittsburgh, Pa.

between this coal and the Lancashire coal in the matter of organization and consequent origin.

The next illustration shows a coal from the island of Cape Breton, Canada, where valuable coal deposits occur. The comparatively slight magnification is sufficient to bring into relief numerous light colored spores on the darker background of modified

wood. In addition one can see here that the matrix shows darker bands containing more numerous spores. These bands will be discussed in a following chapter.

In Figure 27, we get nearer home, for it illustrates

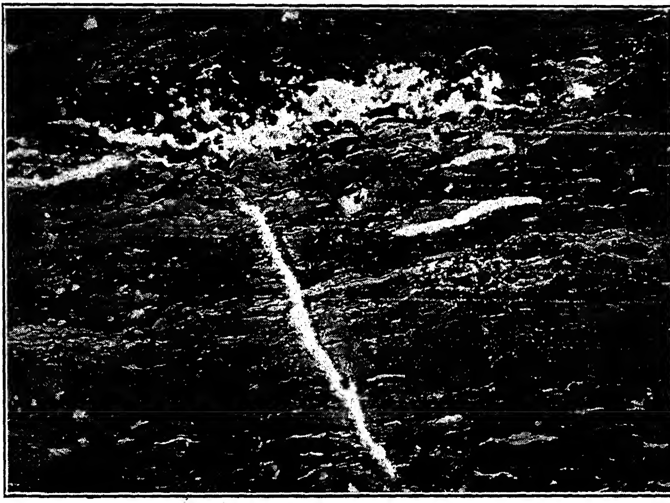

FIG. 28.—Vertical section of bituminous coal from Newcastle, England.

a section of bituminous coal from the Pittsburg Seam, Pennsylvania. The magnification is considerably greater than in the last, because the spores are so small that considerable enlargement is required to make them visible. As in the other cases their light aspect causes them to stand out on the darker background of modified woody material. One of

the flattened spores is considerably larger than the rest.

In the next illustration is shown a coal which is of interest because it comes from the mines of one of the most extensive of the early worked deposits,

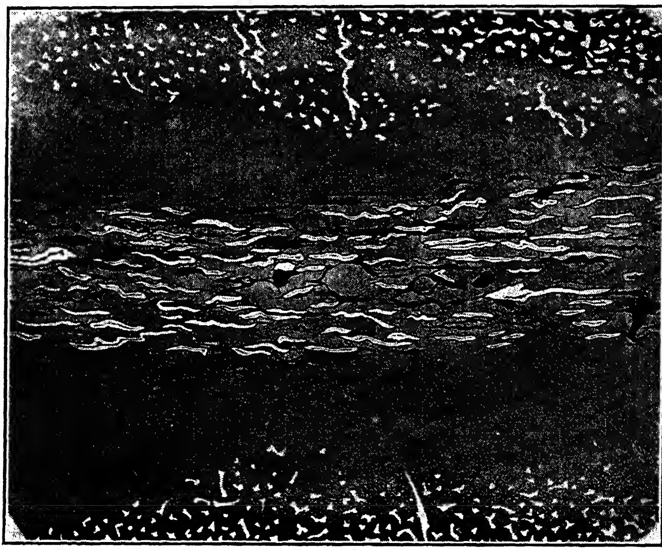

Fig. 29.—Vertical section, highly magnified, of coal from Nova Scotia.

namely those of Newcastle, England. In the upper part appears a fragment of crushed burned wood, such as is frequently found in coals. The ground substance of the coal is mainly of woody origin and the spores are for the most part so small that they can not very readily be discerned. Figure 29,

represents a very highly magnified section of bituminous coal from the Cape Breton field, Nova Scotia. The illustration shows a number of flattened spores included in a matrix, which is darkened by shreds of

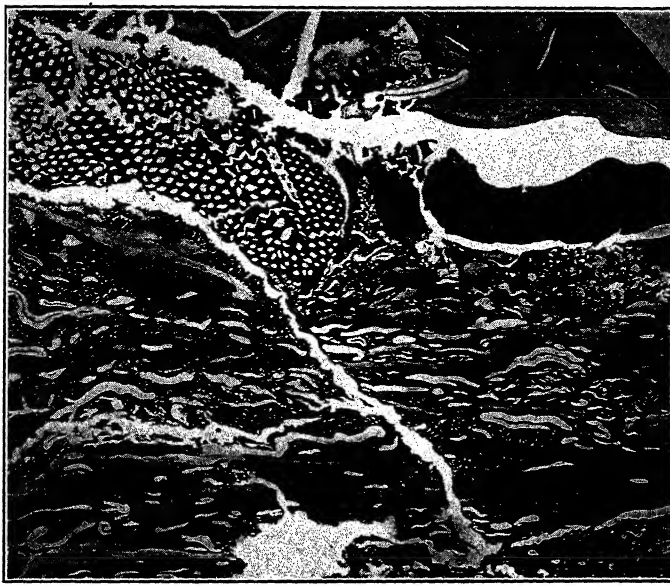

FIG. 30.—Vertical section of bituminous coal from Saxony, showing, among other things, charred wood.

material of deeper hue. In the upper and lower parts of the figure spores are absent, and the substance of the coal is homogeneous except for the presence of indications of woody structure. These indications represent wood, in which the organiza-

tion has escaped complete obliteration by reason of being partially charred. The parts affected by fire are conspicuous not only by reason of the presence of vestiges of structure, but also by their darker appearance.

The next illustration reveals the organization of bituminous coal from Saxony under a similar high degree of magnification. Here the action of fire on the original material of the coals is even more conspicuous than in the coal from Nova Scotia. In the upper region of the figure a piece of well preserved wood is seen, which owes both its state of preservation and its dark color to the action of fire, before it was washed or carried by the wind into the water of the lake. Spores are also abundant together with structureless wood and burned material reduced to a pulverized condition. It is perhaps unnecessary to state that the uncharred wood in the illustration is structureless and much lighter in color than that which is in the condition of charcoal.

The author has examined many hundreds of different samples of coals of many different geological ages, particularly from the United States and Canada. The courtesy of the Directors of the Geological Surveys of these two countries. as well as that of other officials, had made it possible to make a very wide study of the organization of the coals of North America. The investigation of these has taken much time and has involved the preparation of many thousands of sections, showing structures. A

large number of Russian and British coals were also available through the courtesy of M. Zalessky of the Comité Géologique of Petrograd and Mr. James Lomax of Bolton, Lancashire, England, who has himself made a special investigation of the organization of coals.

In addition to the coals enumerated above, a large number from Japan have likewise been investigated, in collaboration with Professor Yasui of the University of Tokio, with results practically identical to those obtained in the case of North America, Great Britain, and Russia. Isolated coals have been examined from Australia, China, South Africa, Germany, Venezuela, Argentina, Chile, etc. The geological range of the coals has been as extensive as their geographical, for all important ages from the Devonian to the present are represented in the preparations, which have been made. The wide variety of material has yielded a singular uniformity in results, indicating that the individual differences of coals are due to varying proportions of a comparatively few constituents.

CHAPTER X

TRANSITIONAL COALS

The present chapter will deal with those coals which are transitional from one category to another and which for this reason are of special importance from the standpoint of the understanding of the composition and mode of formation of coals. Figure A of the frontispiece is a photograph of a piece of coal, which is transitional between channel and bituminous coals. The dull appearance of the lower part of the figure, corresponds to the limits of the cannel, while the brighter upper portion, showing more or less indication of banding, coincides with the bituminous portion. The examination of almost any pile of cannel in a coal yard will reveal pieces showing the transition from one kind of coal to the other.

In the case of certain oil-shales from Australia, the author has noticed a similar transition from the oil-rock to ordinary coal. Here the contrast in appearance, between the two combustibles is more marked than it is between cannel and bituminous coals, since the differences in organization between oil-shale and bituminous coal are much greater. No

illustration of the gross appearance of the passage from oil-shale to bituminous coal is, however, considered necessary in this connection.

We may now turn our attention to the minute organization of the bituminous coal and the cannel,

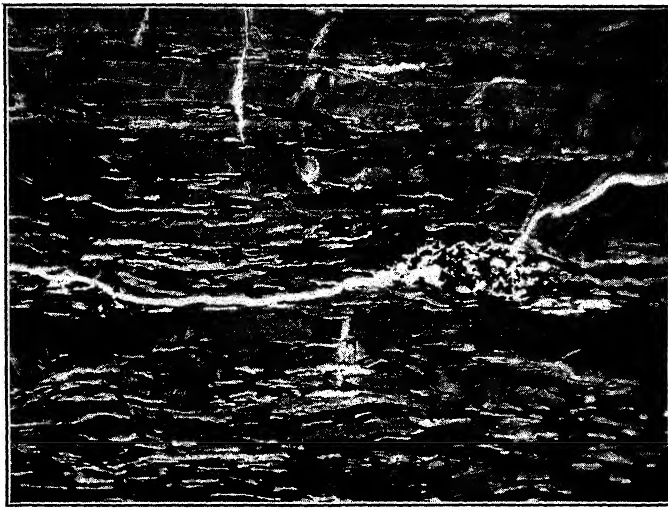

FIG. 31.—Section through the bituminous part of Fig. A of the Frontispiece.

as shown by actual photographs with the microscope, of portions of the block illustrated in Figure A of the frontispiece. The first photograph shows the organization of the bituminous part, under a sufficiently high magnification to reveal its characteristic features. The banded appearance indistinctly shown in the gross, comes out more clearly

in the magnification and is seen to be due to the presence of lighter structureless layers alternating with very dark bands containing many flattened spores. The lighter layers represent woody material which has lost its structure as a result of the united

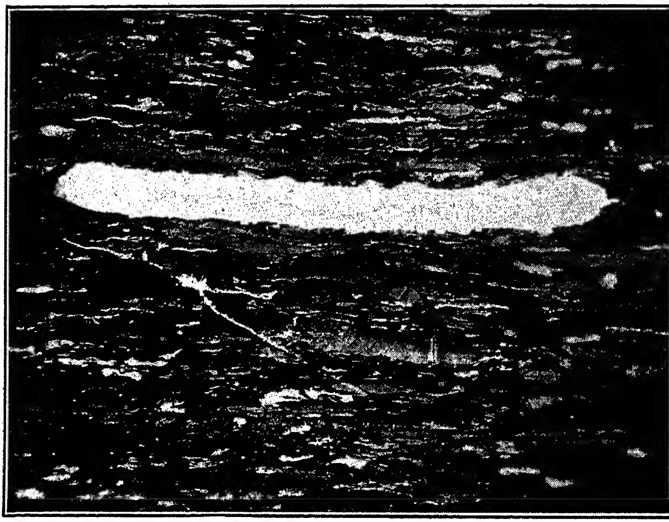

FIG. 32.—Section through the canneloid part of Fig. A of the Frontispiece.

prolonged and secular action of hydrolysis (water action), heavy pressure, and a more or less elevated temperature. The darker zones represent the most perishable remains of plants and animals, laid down in the filling of the coal lake. The collapsed spores are generally confined to the narrow dark zones and more seldom occur in the broader stripes of

modified wood. Towards the right of the middle line of the figure is a small fragment of charred material.

We may now examine the lower dull appearing and homogeneous portion of the coal, in other words, the cannel, under high magnification. There are present a number of spores, differing obviously in character from those found in the bituminous portion of the coal. In the cannel the flattened spores frequently show projecting ends, while in the bituminous portion they are more slender and of equal dimensions throughout. An interesting fact is the presence of a rather smaller number of spores proportionately in the cannel, than are found in the bituminous coal into which it passes. This is contrary to the accepted view in regard to cannel, which is usually considered to be a variety of coal particularly rich in spores. The most striking difference between the microscopic structure of the cannel and that of the associated bituminous coal, is the relatively huge amount of the dark hued constituent and the correspondingly reduced proportion of the component consisting of the much altered remains of wood present in the cannel. The woody constituents of the coal are in fact so scanty that the gross aspect of the coal looks homogeneous and has not the striped appearance of the bituminous portion. It is obvious from the organization of these two types that they represent different conditions of deposition in the ancient lake. In the

case of the cannel the water was doubtless more tranquil and the spores settled to rest in the plastic slime of the lake bottom, accompanied by small fragments of leaves, twigs, etc. Suddenly, perhaps by some change of topography, a slow current began to pass over the accumulated raw materials of the cannel, and this moving water brought with it spores of a different character from a probably more distant source. Mingled with the spores were larger fragments of the members of the trees surrounding the lake, or of the vegetation growing in its waters. Associated with these two more abundant and probably more rapidly accumulated materials, namely spores and woody parts, was a smaller proportion of the slimy matrix, derived in all probability from the ejecta of water animals and from the jelly-like exuviæ of water plants. The relatively large proportion of wood in the case of the bituminous portion, is responsible for the glistening aspect in the gross. Trunks or twigs of trees, when in a condition of transformation into coal, appear as flattened lenses, of black and glistening aspect. Similarly when there is a great deal of woody material in a coal it has the general aspect, which its major constituent presents, when reduced to the condition of coal. Spores too are individually glistening when they have undergone the coaly transformation. The only generally important constituent of the coal, which insures a dull appearance, for the finished product, is the dark matrix, ordinarily most abun-

dant in oil-shales and cannels, but much less so in the case of bituminous coals. The appearance of coal in the gross can accordingly not be safely used as an indication of its richness in bituminous matter or material derived from spores as is very generally assumed. Cannels are frequenty found, which on microscopic examination show very few spores, and the same is probably true of oilshales, although here, the generally light color of the coal is a reliable indication of the preponderating proportion of spores. On the other hand glistening coals are frequently very rich in spores and could be much more advantageously used, where a high bituminous content is desirable, than many cannels. The ultimate test of the usefulness of a coal must accordingly be based either on a chemical or a microscopical analysis, and not on its gross appearance. Much of the cannel coal which is sold to the American consumer might advantageously be replaced by bituminous coal of high content in spores. In Figure 25, on an earlier page is illustrated a bright glistening "Pechkohle," or pitchcoal from Saxony, which contains far more spores than most cannels. By examining the two photomicrographic illustrations of cannel and coal in the present chapter, it will be noted that the bituminous part actually contains more spores than does the cannel. The author has seen coals, obviously cannel in the gross, which contained practically no spores, and hence were unworthy, on that basis, of being included in the category of cannels.

Appearances are consequently often misleading in the case of coals.

The contrast between cannel and bituminous is often very strikingly manifested in transitions from cannel to coal, where the change from one condition

FIG. 33.—Vertical section of striped bituminous coal.

to the other is intermittent or spasmodic. Figure 33, exemplifies this condition under a low magnification. The lighter bands with vertical cracks in them are the woody or bituminoid portions of this so-called striped coal. The dark zones represent stripes of cannel, and they contain as a consequence, not only numbers of spores, but also large

quantities of the dark matrix, characteristic of cannels and oil-shales.

The next figure shows a portion of the last under a higher magnification. The typical organization of the cannel-like and the bituminoid portions comes

FIG. 34.—Part of Fig. 33 more highly magnified.

out more clearly with the greater enlargement. Alterations of a similar nature are extremely common in bituminous coals, and they always depend for their visibility in the gross, on the relative proportions of woody material, of lighter color in section, and of the more perishable dark matrix,

characteristic of cannels and oil-shales. Nothing can be inferred in regard to the proportions of spore material in such coals, from their gross aspect, any more than in the coals which are purely canneloid in appearance. The author has proposed for the alter-

FIG. 35.—Vertical section of bituminous coal from Australia, showing large spores which have been wrongly considered to represent Algae.

nating bright and dark bands, which appear frequently in coals, the terms lignitoid and canneloid. These terms seem to be useful as indicating the essential characteristics of the two kinds of layers.

In concluding the present chapter a few words must be added in regard to transitions from oil-

shales to bituminous coals. The author has observed such transitions in oil-rocks from Australia. The same general principles are involved as in the case of cannels and bituminous coals, with a contrast, however, arising out of the fact that oil-shales are usually much richer in spores than cannels, and as a rule contain little or no woody material. The actual transition from oil-rock to bituminous coal is consequently marked by the more or less rapid intrusion of woody or lignitoid material into the dark matrix of the shale. Sooner or later the dark matrix becomes relatively unimportant as it is more and more invaded by woody constituents. Figure 35, illustrates such a coal in which the fundamental substance is now essentially lignitoid or woody. Within this are included a number of spores, some of which are of the usual flattened type. The larger ones are however, peculiar, and belong to the category so commonly found in Australian oil-rocks, as well as in Torbanite and the bituminous schists of Autun in France. The presence of these bodies, in such a perfect condition of preservation in a matrix consisting mainly of woody materials, altered in the highest degree, obviously supplies a very strong argument against their being of an algal nature, as has been maintained by a number of French and German investigators. They were first diagnosed as Algae by the French paleobotanists, Bertrand and Renault. Later Potonié in Germany, was a strong advocate of this opinion. In a pre-

vious chapter it has been shown that an excellent oil-rock, Tasmanite, is composed, so far as its important organic constituents are concerned, practically entirely of ordinary flattened spores, which are unusually large in size. In American and Scotch oil-rocks or bogheads, organisms closely resembling those found in the oil-rocks of Australia and France have been definitely proved by the author to be spores and not Algae, on the basis of structure. The occurrence of these organisms has been noted frequently in the bituminous coals of both Nova Scotia and Australia, and accordingly it is more than improbable that any of the supposed Algae of oil-yielding rocks are really such. Their resistance to conditions which reduce woody structures to a homogeneous condition puts them in the same chemical category as the spores of the land plants, which show a similar immunity to the influences of time, temperature, pressure, and water action.

CHAPTER XI

THE GENERAL ORGANIZATION OF COAL

FIGURE B of the frontispiece reproduces the general aspect of a lump of coal as viewed at right angles to the layering. The vertical surface of the coal presents an appearance which is very general in coal. Dark glistening bands often very broad and conspicuous alternate with dull stripes, which are even broader. The latter are frequently variegated with narrow shining stripes. Often in addition to the stripes, particularly in the coals of the Middle Western States and of Nova Scotia, masses of charred wood can be made out. When these are examined by boiling in nitric acid, or better, after treatment by the more refined and less injurious methods, devised by the present author, they yield evidences of structure. The general organization of these charred woods will be dealt with at a later stage. The material itself has been variously named and interpreted. One view is that this substance, often inappropriately called "mother of coal," is the result of the action of fungi producing dry-rot, on fragments of wood. This hypothesis seems untenable because if a dry-rot fungus were involved, its

presence could be easily detected in the so-called "mother of coal." The author has examined microscopically hundreds of specimens of this substance in coal of various geological ages and different geographic areas. Only in the very rarest instances, has any indication whatever of the presence and action of fungi been observed. Where fungi are found, they doubtlessly had attacked the wood, while still on land and unprotected by the later water cover, which entirely inhibited the action of wood-destroying organisms.

The glistening bands appearing so conspicuously are known as glance coal, a modification of the German Glanzkohle (glistening coal). From the fact that they are derived for the most part from modified and structureless wood, the present author prefers to call such structures the lignitoid layers.

Alternating with the shining bands are stripes uniformly dull or variegated by narrow glistening lines. The duller portions of the coal contain modified wood in less abundance and in fact usually in relatively small amount. The dull appearance is due to the presence of the dark matrix, so conspicuous a feature of the organization of oil-shales and cannels, which has been described in Chapters VI and VII. In the dull bands spores are also frequently present in great abundance although they may be nearly or quite absent. On account of the possession of the same physical properties as cannels and to a large degree the same organization, the

author has proposed for the dull layers the term canneloid. It must not be assumed from the statements just set down in regard to the dull or canneloid bands of coal that these alone contain spores

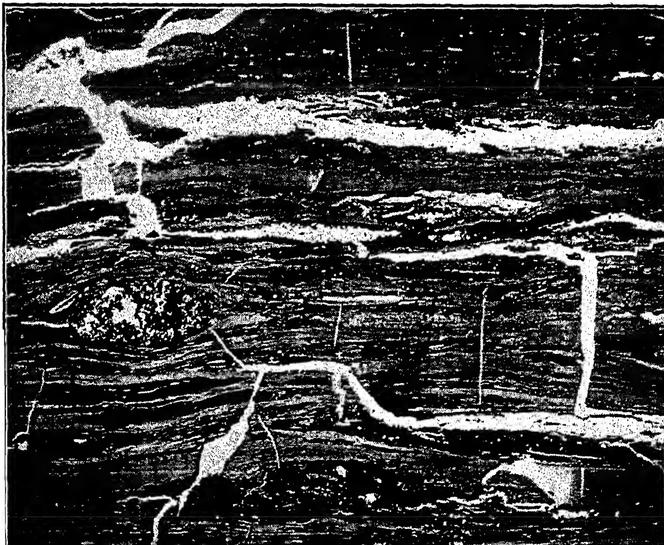

FIG. 36.—Vertical section of bituminous coal from Franklin County, Illinois, slightly magnified.

and the dark matrix. The spores may be present in great numbers in the glance or lignitoid shining bands and a small amount of the deep colored matrix may also appear.

The structural organization, which appears so conspicuously in Figure B of the frontispiece, is

often present microscopically in coal, which to the naked eye presents a somewhat uniform appearance. Figure 36 reproduces a slightly magnified view of a vertical section of such a coal from Illinois.

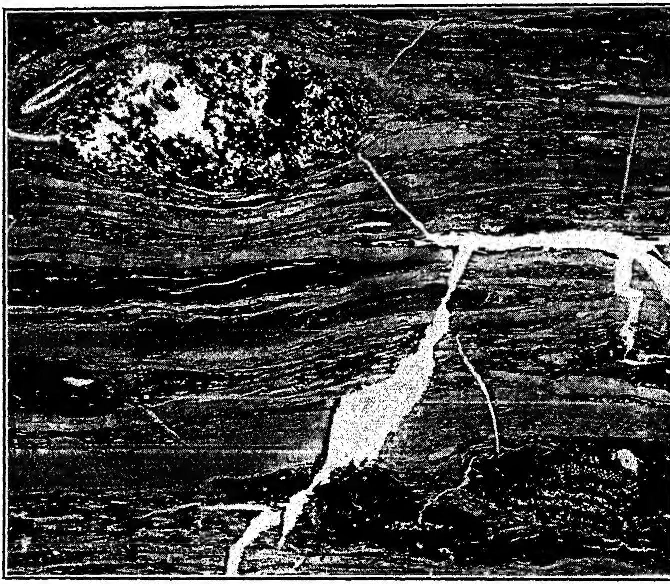

FIG. 37.—Part of Fig. 36 more highly magnified.

The process used in softening the coal for sectioning has caused a number of horizontal cracks and a few vertical ones. The substance of the coal itself presents some degree of variation, expressed frequently as darker and lighter horizontal bands. In places may be seen masses of charred wood; one of these

is particularly conspicuous on the left as a dark rounded mass. The next illustration shows the lower left of the former figure, more highly magnified. Two masses of burned wood are quite conspicuous. One is towards the upper left, and appears clearly also in the former figure. The other somewhat crushed mass of similar material is situated on the lower right. Smaller masses of burned material are scattered throughout the figure. The banded appearance resulting from the alternation of woody and canneloid bands is much more conspicuous than in the lower magnification. It is unnecessary to supply a figure on a higher scale of magnification, to illustrate the detailed structure of the two kinds of bands as figure 34, Chapter X, shows what are identical features in another coal, exemplifying a stage of transition from coal to cannel. It is only rarely that coals are purely woody or purely canneloid; for an extensive and prolonged microscopical examination reveals the fact, that the great mass of coals have fundamentally the same mixed organization and differ from one another only by the varying proportions of modified wood, burned wood, spores and (dark) matrix.

The presence of burned wood scattered throughout the substance of various coals is a feature of great significance from the standpoint of understanding the mode of origin of coal. It is not possible to imagine that such fragments of charcoal could become diffused throughout the mass of the

coal, unless the mineral had been formed originally by transport and sedimentation in open water. If ordinary peat bogs of the higher latitudes of the present are invaded by fire in time of drought, the whole substance of the peat is affected in varying degrees and to different depths, by heat and combustion. In coal we find on the contrary burned wood and material which is entirely free from the action of fire in close and contrasting contact. This situation is realized only in deposits in open lakes and lagoons, at the present time. There seems moreover to be no doubt that the great coal ages belonged to periods in which the climate of the earth was generally warmer and often much warmer than it is, in the same latitudes, today. The presence of so called "mother of coal" in many coals, provides consequently a powerful argument for the transport or open water hypothesis of the origin of coal. Its force is strengthened by the large quantities of spores, which are in general found in coals. It is universally assumed that cannels and oil-shales were deposited in open water, because of their abundant content of spores. This conclusion is reached as a result of the comparison of the structure of oil-rocks and cannels, with the deposits of organic materials found under water in the present epoch. These contain frequently huge quantities of pollen and spores. Since bituminous and similar coals are to an entirely unimagined degree like cannels and oil-shales, in their usually large content of spores, it follows

logically that they too were formed under the protection of a constant cover of open water. Indeed it is impossible to picture the accumulation of huge quantities of dead vegetable matter, in warm climates, such as beyond question prevailed in the ages of abundant coal formation, without the presence of a protective influence such as could most easily and naturally have been supplied by a constant cover of water.

The charred woods in coals can not be appropriately named "mother of coal," as the process of charring insures that they can never be transformed into the fundamental substance of coal. We have consequently to turn to the vocables of other languages than our own to find a more appropriate term. In German the substance under discussion is known as "Faserkohle" or fibrous coal, a name, while accurately descriptive, not suited to the genius of the English language. The French expression "Fusain," indicating a fibrous material, would seem to be the most convenient for use in this connection, particularly if a terminal *e* is added, as has been recently proposed by Miss Stopes. It seems on the whole desirable for the reasons just stated to abandon the faulty term "mother of coal," and replace it by the exact and unmistakable appellation fusaine.

The nature of the fusaine in coals is generally very accurately determinable by appropriate technical methods, such as have been devised in recent years. Such investigations throw an interesting

light on the age of the coal and the nature of the vegetation which has contributed to its formation. Of this only two illustrations will be supplied. The first of these is a longitudinal section of fusaine from

FIG. 38.—Vertical section of the wood of an extinct tree, from coal, Franklin County, Illinois.

a Paleozoic coal from the state of Illinois. This represents the wood of the tree-like genus Cordaites, which was very abundant in the coal-forests of the Carboniferous. Such woods can easily be identified whenever fusaine is abundant in the substance of

the coal. A very large number of coals comply with this condition. Associated with the woods of Cordaites, which was a seed-bearing tree, allied to and probably ancestral to our living Conifers, are found,

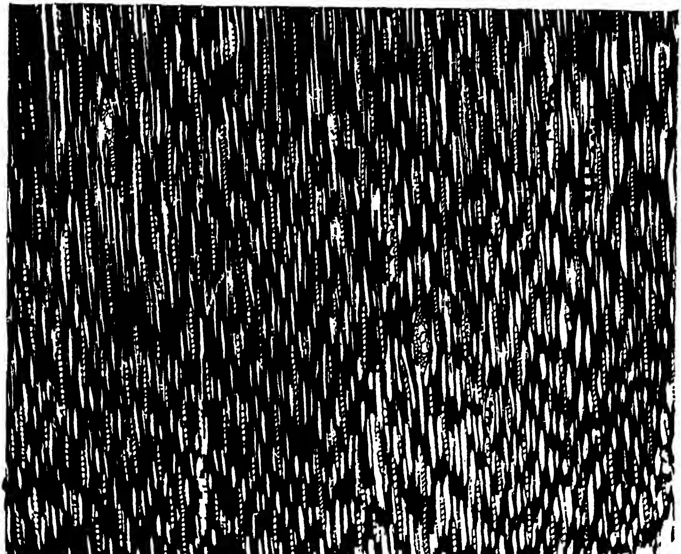

FIG. 39.—Vertical section of charred wood from Mesozoic coal from the state of Montana.

usually in abundance and well preserved, woody parts of tree-like Club mosses (Lepidodendrids and Sigillarians), and of gigantic arboreal Horsetails (Calamites), the ancestors of our lowly Scouring rushes or Equieseta of today. If there were no other evidence available, the presence in coals of the

woods of Cordaites, Lepidodendrids, and Calamites, would very clearly indicate the Paleozoic age of such combustibles.

The following illustration supplies a longitudinal view of the wood of an extinct Conifer from a Mesozoic (Cretaceous) coal. It is clearly diagnosable as belonging to the trunk of a tree closely allied to the surviving Bigtrees and Redwoods of the Sierra Nevada and the Coast range of California. The structure is so perfectly preserved that Professor Torrey, who has discovered and described the wood, is able to assign it to a definite species under the name of *Sequoioxylon montanense*. This and similar species described by Professor Torrey and others connect the two surviving but almost extinct species of Sequoia with the Pines. It is obvious, consequently, that the study of charred fragments of wood, which have fallen into the coal lakes of earlier geological ages, is likely to contribute in a large and important way to the past history of our forest trees. The evidence from coal is further very much more abundant and reliable than that derived from any and all other sources.

A not uncommon structure in coal is the remains of the outer skin or epidermis of plants. There are in fact exceptional coals, known as leaf or paper coals, which are very largely made up of the epidermal layers of extinct plants. A notable illustration of this condition is supplied by the Toula coals of Russia, which belonged to the Culm formation.

In these it is easy to separate pieces of considerable size, representing the outer integuments. One of these is shown in the accompanying figure. It is possible to identify the tree from which the skin was derived as a species of Bothrodendron, a type of

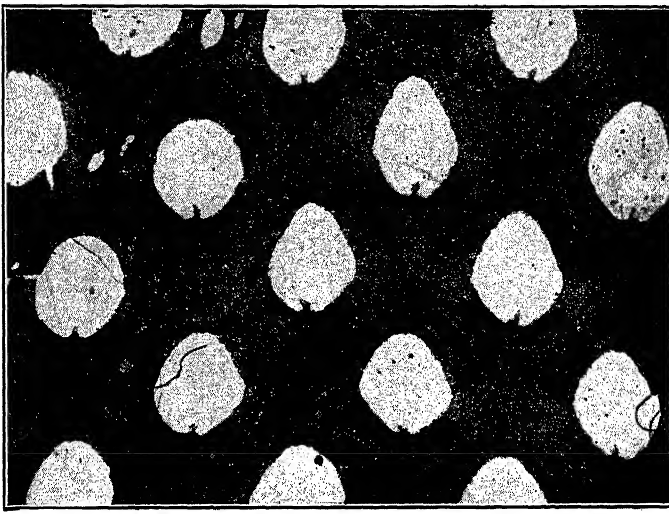

FIG. 40.—View of the epidermis of a Lepidodendron from the Toula coal of Russia.

Lepidodendroid or arboreal Club-moss. The holes appearing in the illustration represent the places where the leaves were attached to the stem, when the plant was a living member of the forest. The indications here are that the branches of a number of trees decayed on land until nothing but the resistant epidermal layers were left. These were later

washed into the waters. It is a curious fact in the case of plants that the skin or epidermis is of all the tissues the least prone to decay, since it very slowly falls a prey to the organisms, which quickly annihilate the soft parts and more slowly even the hardest woods, unless continuously covered with water. On account of this extreme resistance of the epidermis to the ravages of time, the leaves of extinct plants, in which the epidermis is unusually strongly developed, constitute the most abundant record of the former occurrence of plants which resemble or differ from those now living. It is unfortunate that the shapes are not always reliable indications of affinities, so that many erroneous statements have been made, in regard to the relationships of extinct plants, surviving only in the impressions and epidermal structures of their leaves. The late Professor Nathorst of Stockholm has made valuable additions to our knowledge of plants of the past by the microscopic study of their epidermal layers or outer integuments.

Other very resistant structures of plants are the corky tissues and the spores. The latter are really only a special case of epidermal layers, since each spore is coated externally by a resistant and frequently very thick coat, which protects it from injury and prevents premature germination. Many instances of the preservation of spores in coal have been supplied in the preceding pages, and it is accordingly unnecessary to dwell specially on that

subject in the present connection. The accompanying figure, which illustrate the organization of a bituminous coal from the Carboniferous of Scotland, shows the contrasting colors of spores and epidermis, which help to make them recognizable in thin slices

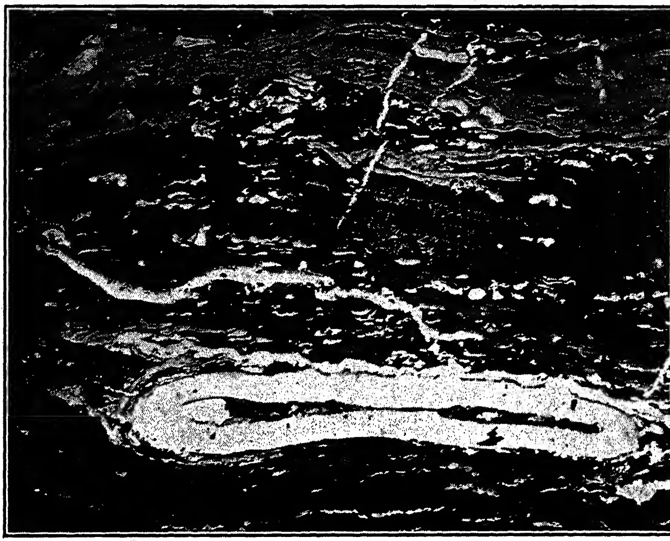

FIG. 41.—Section of bituminous coal from Scotland, showing in its upper region fragments of epidermis.

of coals. In the lower part of the figure is a huge flattened spore, surrounded by a number of smaller and less recognizable spores, as well as by modified wood and the dark matrix, so often mentioned in these pages. In the upper portion of the illustration are found a number of fragments, which are

darker than the spores but not nearly so deep in hue as the modified wood forming the mass of the coal. These represent epidermal structures, which have a deeper shade than the golden yellow of the spores and on the whole do not oppose so strong an obstacle to decay as do the spores. When epidermal structures and spores are exposed to the decay-producing organisms, which flourish where the substratum is merely moist and not submerged, they are frequently considerably corroded. Conditions of this kind are responsible for the statement that micro-organisms play a considerable part in the elaboration of the fuel stuffs united under the category of coals. The facts brought forward in an earlier chapter seem however to negative conclusively any such activities as a usual condition in the origin of coal. Vegetable materials kept continuously under water suffer only age-long or secular change, and the action of microscopic organisms destructive of wood and similar substances is entirely excluded. Further, in relatively warm climates such as undoubtedly prevailed in the coal periods, no considerable accumulation of vegetable remains on wet land, such as are found at the present time only in high and consequently cool latitudes, was possible. Since the only imaginable manner of storing up material of dead plants, at high temperatures, is the subaqueous and since continuous water cover eliminates the action of microscopic wood-destroying organisms, it follows logically that micro-organisms

have played no important rôle in the elaboration of our fossil fuels, athough there are statements in number to the contrary. It is perhaps well to point out in this connection, and as an example of the antiseptic properties of bog water, that in the days of sailing ships and long voyages, the water butts were always replenished if at all possible, from lakes and lagoons, more or less completely occupied by vegetable remains. It was found as the result of practical experience, that such waters kept sweet, where the best spring water quickly putrefied and became undrinkable. The Dismal Swamp of North Carolina and Virginia was particularly in repute for use as a water-supply for ocean-going shipping in the sailing days. Thus in practice brown bog water proved more useful.

As indicated in the previous paragraph the corky tissues of plants are also resistant to change and survive for a long time the combined action of hydrolysis and pressure. In many ancient plants such as the Lepidodendrids or tree-like Club-mosses and the Calamites or arboreal Horsetails, the corky layers were well developed on the outside of the plant as a protective device. Corky tissues can often be clearly recognized in coals and retain their organization, under the action of forces which have completely obliterated the structure of all remains of wood, except those which have been charred by fire. It is not necessary to introduce illustrations in this connection. Corky remains in coal are easily

distinguished from woody, by the absence of rays, such as are characteristic of wood.

To summarize the various subjects considered in the present chapter, it may be stated that coals frequently present a banded appearance. This is due to alternations of stripes of coal of different composition. The shining bands, often known as glance, are composed mainly of modified wood, although a greater or less quantity of spores may also be present. The dull alternating stripes are normally composed of a very dark matrix, containing a greater or smaller amount of spores and modified wood. In addition to the bands in coal, organized as above indicated, there are frequently remains of charred wood, with structure preserved in proportion to the degree of charring. When the banded organization just described is too minute to be visible to the naked eye, it may often be detected in microscopical thin sections. Of all structures found in coal, those most likely to maintain their original organization are spores, epidermal layers, and corky structures. Wood usually only retains its structure in coal, when it has been previously charred by fire. The action of fungi in a biochemical manner is of little or no importance in connection with the elaboration of coal from the crude original materials. This is clear because the conditions under which vegetable matter may reach large accumulations, in warm climates, such as those of the periods of greatest coal formation, exclude the action of micro-

organisms. Other things being equal, the chemical elaboration of coal depends consequently on its age and on conditions of pressure and of temperature. Micro-organisms have no important influence upon it after it has been laid down under water cover. Certainly they did not exercise any action on its structure in the secular time, during which it was becoming deprived of oxygen, was undergoing compression, and was suffering loss of its volatile constituents. It may accordingly be stated that the influence of the lower organisms in the elaboration of this invaluable mineral is entirely negligible. Any action in this direction must in any case, have taken place, before the raw materials of fossil fuels, after a longer or shorter transport, came to rest under the surface of the constant or rising level of the waters.

CHAPTER XII

THE COKING OR CAKING COALS

This is an increasingly important category of coals, since the greatest general value industrially, belongs at the present time, to coals which can give rise, by dry distillation, to the fuel product coke and at the same time yield those invaluable by-products which figure so largely in chemical industries, involving the manufacture of explosives, dye-stuffs, medicines, solvents, printing inks, disinfectants, etc., etc. It is accordingly extremely important to examine the organization of the coals belonging to this group. We shall naturally do best to begin with the structure of coking or caking coals of the highest grade. Peculiar technical difficulties are connected with the structural study of coals of this type. They are apt to be rather tender and friable and as a consequence very great care is needed in bringing them into a condition suitable for the cutting of the extremely thin section, necessary for the clearing up of their organization. It was only after many unsuccessful efforts, that the present author was able to devise methods to overcome the unusual difficulties connected with the investigation of these coals.

Two coking coals of very high grade are those of the Connelsville basin in Pennsylvania, and the Pocahontas field in Virginia. Of the two the latter is the better coal, as it contains a higher proportion of carbon. The best metallurgical cokes are extremely hard and contain a very large percentage of fixed carbon. The durable texture of good metallurgic cokes is asserted to be of great importance in connection with the technique of the blast furnace, as the coke has, in the process of smelting, to support for a prolonged period a great weight of iron ore. If it is friable, as is the case with much of the coke resulting from the manufacture of illuminating gas, it is unsuitable for smelting purposes, and is of much less value even as a domestic fuel. The Connelsville and Pocahontas cokes are free from these objections and form the basis of the highest metallurgical industries.

It has long been known that oil shales and many cannels are incapable of being coked. The same statement holds true for true anthracites, such as those of Pennsylvania. Many coals are readily coked when they are first brought from the mine, but after prolonged exposure to the atmosphere, they lose this capacity to a large degree. One of the valuable discoveries made in recent years, is that many coals, which are under the usual treatment, incapable of giving rise to coke, will fuse and cake, if they are pulverized, and, as uniformly as possible,

exposed to a high temperature, throughout their mass.

Coking coals are at the bottom of all modern metallurgical processes, and the practice of utilizing the very valuable by-products of the coking process

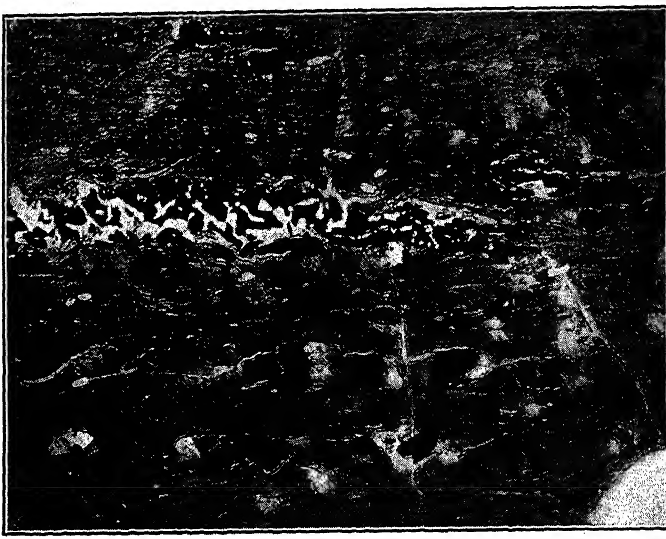

FIG. 42.—Section of coking coal from Connelsville, Pa.

is becoming more and more common. Originally all the American coking ovens were of the so-called bee-hive type and wasted completely the volatile exudates and emanations of the coking process. The great value of the distillation products of coking coals is being more and more utilized by the construction of by-product ovens of various types,

which supply the raw material for many chemical industries, fundamental to our civilization.

The brief statements introduced above, make it clear that coking coals constitute a category of coals, which is of inestimable value from the standpoint of the basal industries of our present civilization. It is now pertinent to inquire what is the typical structure of coals included under this heading. Figure 42 illustrates the organization of a vertical section through a piece of coking coal from the Connelsville field, under high magnification. An examination of the illustration reveals the fact that the coal under consideration is practically entirely composed of material corresponding to modified wood. No spores have been seen in the coals from Connelsville and it is accordingly probable that they are not an important constituent of the coals of this field. Through the center of the figure passes a black mass, in which the structure has not been completely obliterated by pressure. This is a fragment of burned wood, which, as is usual, has been preserved from the complete loss of identity which generally characterizes all but charred woody remains in coal. Connelsville coal produces a very high grade coke containing, according to an analysis of the United States Geological Survey, 88.7% of fixed carbon. In this respect it presents a very striking contrast to coals of later geological age or of higher volatile content. In the coke of these the fixed carbon may not be much more than half as

high as in coke produced from fuels of the Pocahontas field or the Connelsville basin.

The coking coals of the Pocahontas field have virtually the same organization as the Connelsville coal figured above. It will accordingly be clear to the reader, that an outstanding feature of the organization of coking coals is the presence of a preponderating amount of material which is of woody origin. It has been pointed out above that pure spore coals, such as oil-shales and certain cannels, can not be coked. Further coals which contain some spore material together with a great deal of matter of woody origin are able in various degrees to furnish utilizable coke. In the case of such coals, however, the ordinary coking processes do not result in the production of a durable combustible, and as a source of coke they are accordingly less satisfactory, especially when manipulated in ovens which do not permit the exploitation of their relatively abundant fluid or volatile by-products. An important avenue of activity, in North America, will in the future be supplied along the line of improvements in the winning and utilization of the by-products of coals of lower grade and less purely woody organization.

A study of the structure of high grade coking coals has led the author to the conclusion that such coals are almost exclusively composed of modified wood, usually to the almost complete exclusion of the spores, which are a common and almost universal constituent of the mass of other coals.

In both the Pocahontas and the Connelsville coking coals, large quantities of burned woods are present, diffused throughout their substance. As has been pointed out above, the only reasonable explanation of these isolated fragments of charred wood through the coals, is that afforded by the transport hypothesis of the origin of coals. It is in fact not conceivable that the deposits could have been formed in any other way. The apparently unjustifiable hypothesis, that the charred fragments in the coal are not what they seem to be,—but portions of wood, which have suffered from dry-rot, due to the activities of *Merulius lacrimans* or some similar fungus, does not stand the test of investigations of actual structure. In the case of the destruction of wood through the agency of dry-rot, the causative organism is actually present and provides unmistakable evidence of the origin of the ravages by the numerous perforations of the walls of the elements of the wood. It is not necessary to demonstrate the truth of this assertion photomicrographically, since the causes of the decay of wood are well understood by mycologists and can not be used as an explanation of the origin of fusaine or so-called "mother of coal." The latter only in the rarest instances, which are to be explained on the hypothesis of the infection having taken place before the wood was submerged, contains any evidence of the presence of mycelial filaments of wood-destroying organisms.

It has been shown in an earlier chapter, that it is possible for homogeneous coals to originate from the vegetal material, which is found mainly present in the coal-balls of certain seams in England, Germany, and Russia. Figures 22 and 23, Chapter VIII, vouch for the truth of this assertion. The coal surrounding the coal-balls in fact strongly resembles the coal of the best coking deposits, such as those of Connelsville and of the Pocahontas field. It does not always happen however that a homogeneous woody coal will coke, when subjected to dry distillation in a coking oven. Anthracite, as will be shown later, is often of highly uniform woody derivation, and yet it is quite incapable of being transformed into coke on account of the condition to which the woody matrix has been reduced by the practically complete loss of volatile matter. Many coals which are quite woody in composition, are not in the chemical condition to give rise to coke. A good coking coal, should, in accordance with the principles deduced above, be composed very largely of materials, which in the raw condition were mainly woody and which by the changes due to temperature, pressure, hydrolysis and time, have undergone the appropriate degree of chemical alteration.

If the principles stated in the preceding paragraph are sound, it ought to be possible to produce coke from materials which are purely lignitic, that is, wholly derived from modified wood. Obviously the crucial condition will be found in the case of a

trunk of an extinct tree, which as a result of the processes accompanying fossilization has been entirely transformed into lignite. Here no complications of the problem are introduced by the presence

Fig. 43.—Piece of a Cretaceous tree which has been transformed into coke by heating in a retort.

of spores, fusaine or the dark matrix, characteristic of those coals partially or wholly of a dull lustre. In the accompanying illustration is shown a sample of coke thus obtained. A piece of the wood of an extinct Araucarioxylon (a coniferous wood) was ex-

posed for some time to strong heat with the exclusion of air, in a covered retort. The result is the production of typical coke. The porous character of this can readily be seen by inspection of the illustration and is exactly that found in the case of natural or artificial coke produced from coal, suitable for this purpose. It has been stated above, that the possession of a purely woody structure, does not necessarily insure that a given coal will prove suitable for the coking oven. The modified woody material in the coal must have reached the precise degree of chemical change which will insure its melting when exposed to strong heat. The material illustrated in this connection, was derived from a Cretaceous Araucarioxylon, from Kreischerville, Staten Island, N. Y.

An interesting confirmation of the truth of the author's hypothesis of the origin of coking coals has been recently supplied by a natural coke, submitted by his colleague Professor J. B. Woodworth for identification. It was accidentally found just beneath the surface of the ground on Cape Cod and sent to the Geological Department of Harvard University. It proved, on examination, to be a very typical coke, derived by the exposure to heat of wood in a lignitic condition. The wood is of recent origin and is coniferous in organization, being probably that of the hemlock or possibly that of the fir. The condition of preservation in the lignitic portions, not transformed by heat into coke, left some-

thing to be desired, and an entirely satisfactory diagnosis has not yet been reached.

We are brought by the facts described above to a very interesting conclusion. It has been pointed out in an earlier chapter, that the metallurgical manipulation of iron was originally effected by the use of charcoal, produced by the dry distillation of wood in charcoal kilns. In the latter process the volatile matter of the wood is driven off and a condition approximating pure carbon is reached. For many centuries, charcoal was the basis of the industries involving the smelting of iron, and the practice of smelting operations was as a consequence confined to areas where the forests were still abundant. The large consumption of charcoal in the inefficient iron-smelting processes of the earlier centuries ultimately exhausted the forests, so that the smelting furnaces had more and more to be transferred to wild and still heavily forested regions. By the middle of the seventeenth century, the accessible raw materials of charcoal had been largely consumed and the English iron industry as a consequence suffered a serious decline. Four fifths of the national needs of iron were imported from abroad and not, as previously, supplied by native smelting plants. Jevons attributes to this condition the almost stationary condition of the population of Great Britain, which lasted for nearly a hundred years. About the middle of the eighteenth century the English smelting industry achieved a new lease of life through the final

development of the art of smelting iron with coal. The coal was coked and then employed for the reduction of iron from its ores, precisely as charcoal had been employed in the earlier centuries of the age of iron. As a result of the development of the art of smelting ores by means of coke, the British iron industry entered on a career of pre-eminence, which on the *per capita* basis, is still the greatest in the world. Not long after smelting by means of coke was invented, England became the most abundant producer of iron in Europe, although Sweden still maintained first place in the matter of quality. At the present time the United States is the greatest producer of iron and steel, although the status of Great Britain on the basis of population is still very high. The first place in quantity production came to America toward the end of the nineteenth century.

The United States are likely to maintain their leadership in the iron industry. The large supplies of excellent coking coal, lying conveniently near the seaboard make this pre-eminence apparently beyond question. It is interesting to note, that the best coking coals of North America, namely such as those of the Pocahontas field and the Connelsville basin are on the reliable evidence of their internal structure, derived from almost exclusively woody materials. Thus the charcoal of the earlier practice of the metallurgy of iron, has been appropriately replaced by coals, which, like charcoal, are

derived from wood. The treatment which transforms coking coals into coke presents a close parallel in its essential features to the older charcoal industry. The products are however of much greater value to humanity than are those which result from the dry distillation of wood.

In no case is national well-being more closely bound up with an abundant supply of utilizable coal than in the basic metallurgical industries. Jevons pointed out long ago, that the prosperity of Great Britain began with the modern exploitation of her coal fields. The centers of industrialism in the British Isles were at the same time the centers of coal and of population. From the middle of the eighteenth century on, the growth of population was uniformly large and resulted not only in the great multiplication of the people of industrial Great Britain, but likewise supplied material for a huge emigration to other English-speaking countries and to the colonies. The United States of America are beginning to feel the same influences and the twentieth century will doubtless see changes closely paralleling those which have taken place in the mother country, but on a much larger scale.

CHAPTER XIII

ON THE ORIGIN OF ANTHRACITE

Coals of this group are distinguished by their very high content of fixed carbon, and as a consequence they burn with a clear smokeless flame, and provide an enduring fire. These qualities make anthracite of the greatest value for domestic use and also for certain industrial processes. The great concentration of coals of this category contributes also to the esteem in which they are held. It has been very generally inferred that anthracites are derived from coals of less content of fixed carbon by a progressive devolatilization. Since it has been generally assumed in the past that ordinary bituminous coals have come from terrestrial peat as the result of the united action of lower organisms, pressure, temperature and hydrolosis, it is often asserted that fossil fuels represent a continuous series beginning with peat and ending with anthracite. It is clear, however, that even if the obviously erroneous hypothesis of the derivation of bituminous coal from peat were admitted to be true, there would still be difficulties in demonstrating the derivation of anthracite from bituminous coals.

It has been shown in preceding chapters that bituminous coals are not derived from terrestrial peat such as is formed in high latitudes in the present epoch. A more accurate name than peat for the raw materials of bituminous coals is muck or organic sediment. The term sapropel, which has been proposed by Potonié in Germany is unsuitable because of the hypothesis which it implies. According to Potonié the fine materials, which occupy the bottoms of lakes and ponds, and which with the progressive filling of these, assume an ever coarser texture, are the result of extreme putrefaction. In fact the name sapropel indicates this extremely hypothetical view. An examination of the actual deposits accumulating in bodies of water in eastern North America from Canada to Florida inclusive, seems to definitely negative the sapropelic hypothesis. An interesting inconsistency in connection with this putrefactive hypothesis is, that although the plastic mass muck occupying the bottoms of lakes, ponds, and other still waters, is considered to represent the result of the extreme disintegration of the higher plants, it is nevertheless maintained to include within its matrix, the structural remains of such highly perishable organisms as the Algæ. The author and his students, during the course of a decade and a half, by means of probing instruments of precision and by microscopic examination, have never been able to detect the remains of other than mineralized Algæ, such as

Stoneworts and Diatoms, in the substance of the aqueous organic deposits of the present epoch. These investigations cover the eastern provinces of Canada and extend southward to the state of Florida. The sapropelic hypothesis presupposes that a strong biochemical action is taking place in subaqueous deposits, which brings about their more or less rapid chemical disintegration through the activities of the lower organisms. There seems to be no good ground for such an hypothesis, as the actual study of such deposits shows that they are in general composed of material in a relatively static condition chemically and remarkably free from any lower organisms capable of effecting marked chemical or other changes. The most delicate structures are preserved throughout intact, with the exception of the extremely perishable Algæ. The presumption of marked changes due to decay, in lacustrine and similar accumulations seems to have arisen out of the contemplation of the conditions present in contemporary accumulations on land, in higher latitudes, known as peat (German, *Torf.*, French, *Tourbe*). In the peat beds of the bogs or tundras of northern Europe and America, the superficial layers represent materials which are relatively unchanged, and which in fact grade into actually living plants. At a variable distance below the surface of the deposit, disintegration favored by moisture, high temperature, during the short summer and the frequent presence of air, during dry

spells, sets in. As a consequence the lower layers of the peat assume a darker hue and an increasingly homogeneous texture, resulting from the structural and chemical breakdown of their constituents. A microscopic examination of such darkened peat reveals the presence of numerous destroying organisms, both bacterial and filamentous. While it is true that the lower layers of peat are in a condition of disintegration due to the action of lower organisms, it is emphatically untrue that similar conditions can be found in material kept continuously covered by water, as is the case in lacustrine and similar deposits of remains of plants. If any marked symptoms of decay are present here, they are found in the upper layers formed after the filling of the lake through the accumulation of terrestrial remains. These topmost additions are periodically exposed to air as the result of drought, and if a high temperature coöperates with aëration, the disintegration is correspondingly rapid.

The above statement has been made because it has sometimes been suggested that anthracites owe their high carbon content to the action of microorganisms in the earlier phases of their formation. There is nothing to show that biochemical action, that is, the change due to the life-processes of lower organisms, has had an important influence in the origin of any important category of coals.

The investigation of anthracites is accompanied by serious technical difficulties because of the black

opacity of these coals. The carbon is also in such a condition of concentration and consequent hardness that it is very difficult to secure satisfactory sections. Only after many efforts has it been found possible to prepare sections of anthracites which reveal their structural features. In many cases from one to two years of treatment are necessary to bleach and soften the coals to such an extent that they can be satisfactorily cut into thin sections, revealing structural details. The author has worked for a decade and a half on these coals before securing results even measurably satisfactory. On account of the length and laboriousness of the processes it was further found necessary to concentrate upon limited material. Pennsylvania anthracites from Scranton have been intensively investigated and the results derived from these coals are described here. It is probable however that they are applicable to a wide range of similar coals.

The material has to be subjected for nearly two years to the action of chlorate of soda dissolved in concentrated hydrofluoric acid. This reagent is a very valuable one as it softens and bleaches coal, without the oxidizing and macerating action of *aqua regia* as ordinarily compounded, or of a modified *aqua regia,* devised by the author, in which the usual hydrochloric acid is replaced by hydrofluoric acid. When the solution of chlorate in hydrofluoric acid has been obtained, the resulting fluid is ordinarily diluted by one-third to one-half of its volume

of water. After the coal has been subjected to its action until it begins to show a distinctly brown hue on the outside and is quite soft, it is then washed over night in slowly running water. The water is replaced by strong alcohol which is in turn replaced by phenol (carbolic acid). The latter reagent exercises a further softening action on the treated coal and extracts from it a large amount of dark brown color. The phenol is washed out with water or alcohol and the pieces of anthracite are embedded finally by a process described by the author (Methods of Studying Coal, Science Conspectus, Vol. 6., No. 3, 1916, pages 71-76), in the commercial nitro-cellulose, known as Parlodion. Very thin sections two to three micromillimeters in thickness (from two to three twenty-five thousandths of an inch) are cut on the microtome by means of a very sharp hard-tempered knife.

The usual organization of anthracite is clearly that of a coal derived from predominantly woody constituents, which have undergone a complete obliteration of structure, precisely as in bituminous coals. The coal-ball coals, we know from the organization of the petrifactions or concretions found within them, to have been mainly formed of the vegetative remains of plants. A similar origin of high grade coking coals is assumed from their structure, although as yet no petrifactions have been described for the Pennsylvania or Virginia coking coals, which would throw light on the nature

of their unmodified constituents. It may accordingly be assumed that the anthracites of Scranton, Pennsylvania, of which we have examined a number of samples, have been derived in the main from woody materials, often to the almost complete exclusion of spores. In this respect they resemble in fact the coals of the adjacent Connelsville and Pocahontas fields. Like the Connelsville and Pocahontas coals, they contain remains of charred wood, which are in some cases considerable, but always much more compressed than is the case with the fusaine or "mother of coal" of coals of lower carbon content. It may be further assumed that like the coal-ball coals and the coking coals their raw materials were deposited in open water. The frequent diffuse occurrence of fragments of modified charcoal throughout their substance seems to vouch sufficiently for this conclusion, as vegetable accumulations of the present day, with charred material included sporadically in their mass, have invariably been laid down in open bodies of water.

It is not unlikely that the mass of Pennsylvania anthracites will show themselves, after extended investigation, to have a similar organization to that found by the author in a number of samples of Lackawanna anthracite from Scranton. It is not improbable, however, that in some instances spores will be found in greater or less abundance, by reason of the probably lacustrine accumulation of the raw materials of all anthracite coals. In view of

the uniform absence of spores in the coking coals of the Connelsville basin and the Pocahontas field, however, it is not unlikely that spores may prove to be quite generally absent or sparingly present in anthracites. It is naturally impossible to predict on the basis of observations made on a few high carbon coals of Paleozoic age, from Pennsylvania, what the organization of coals of a similar high carbon content, from other fields and from other geological ages of the world, may reveal, under appropriate technical manipulation.

Assuming that anthracites, like the mass of other coals, on the evidence of structure, have been derived from materials originally accumulated under open water and not in peat bogs, the question arises, as to how they have achieved their extremely high percentage of carbon. The reasoning adopted in the case of coals with a smaller amount of fixed carbon, seems to apply equally here. It has been argued in the foregoing pages, that biochemical action is of relatively slight importance in effecting the changes, which bring about the concentration of volume and increase of carbon content, in the fossil fuels known as coals. Obviously biochemical changes, if they are to be effective, must in general take place at an early stage in the modification of the raw materials of coal. If they do not take place then their action is clearly indefinitely excluded. The aquatic origin of the mass of ancient fossil fuels, seems on the evidence available to definitely elimi-

nate bacterial or fungal action. Further the effect of hydrolysis, or water action, must be slight in the origin of anthracite coals as such, since the later changes, which result in their high degree of carbon content are necessarily carried out without the influence of water, that fluid having long disappeared. We are accordingly reduced to the agencies of temperature and pressure, in accounting for the origin of the characteristic properties of anthracitic coals. It is now rather generally assumed that heavy pressure and perhaps a greater or less elevation of temperature are efficient agencies in the production of coals of the anthracitic category from fuels of a lower grade and higher volatile content. This assumption seems to be justified by the phenomena found when coals of lower grade are locally exposed to great heat and pressure as for example as a result of the intrusion of rocks in a molten condition. The changes produced as the result of the irruption of molten rock into a seam of coal naturally depend in large measure on the nature of the overlying strata. If these are much cracked or jointed as is apt to be the case in a region where the rocks have been contorted and fractured in the process of the formation of mountains, the gases and exudations produced by heat and pressure will have a chance to escape and a condition closely resembling anthracite is the result. If the pressure is not so great and impermeable strata confine the products of distillation, set free by the irruption of molten rock,

a natural coke is formed. If the changes are more gradual and involve a large extent of superficial. contortion in the processes of mountain-building, there will be a progressive fissuring or jointing of the rocks overlying the coal. The heat and pressure more gradually brought to bear in the slow convulsions of mountain-making, develop and drive out the gases and exudates or fluids from the coal. The fissuring in the rocks above allows the products of distillation to escape and an anthracite coal is produced. The probable conditions leading to the formation of anthracites from their raw materials have recently been admirably summarized by David White (The Origin of Coal, Bulletin 38, United States' Bureau of Mines).

Anthracites are in general coals of regions in which mountain-building and even volcanic influences have been strongly in play. They are found for example in the more disturbed region of Pennsylvania, in the Rocky Mountains of the United States and Canada, and in the mountainous regions of Wales and Scotland.

CHAPTER XIV

BROWN COALS

This group of coals is distinguished by its brown color, sometimes obscured in the mass by a black and glistening appearance. In its more advanced condition, brown coal resembles bituminous or subbituminous coal in general aspect. Even in such cases, however, it makes a characteristic brown mark when rubbed on a white surface. The term lignite is often used interchangeably with brown coal but this practice seems to be open to serious objection from the standpoint of accuracy, since lignite strictly means a substance derived from the modification of wood. It will be obvious to the reader from what has been stated in the foregoing pages, that wood is not always the predominant constituent of the raw materials of coal. It follows that it is better to use the term brown coal for a mixture of materials such as characterize coals in general and also as a consequence the use of lignite is better restricted to conditions, where it is certain that the fossil fuel, is composed wholly or at least mainly of modified wood.

The brown coals grade almost imperceptibly into

peat on the one hand, and into bituminous coals on the other. They in fact constitute the link between the raw state represented by coal in its original condition of lacustrine muck and the somewhat highly modified form known as bituminous coal. In brown coal a considerable degree of transformation due to hydrolysis and pressure has taken place but the fuel still retains the brownish hue of the mother substance, and also a large proportion of the oxygen and hydrogen of the original carbohydrates.

Naturally brown coals are in general modern, since time, other things being equal, is a very important factor in the elaboration of the higher grades of coal, in which the ratio of oxygen to hydrogen is much reduced beyond that present in the carbohydrates, constituting the original vegetable materials. There are however, coals of the Paleozoic period, which still retain a brownish hue and other characteristics of brown coals. This is notably the case with the Paleozoic coals of the Moscow field in Russia. On the other hand, where the changes due to temperature and pressure have been accentuated, as in mountainous regions, we very often find quite modern coals presenting the high carbon content, which is more usually found only in the older coals.

The general organization of brown coals naturally closely resembles that of coals formed in earlier geological epochs. The nature of the constituent plants is different, however, because of the striking changes which time has brought about in both the

climates and the plant populations of our earth. In the Paleozoic, Ferns, Club-mosses, and Equiseta (Horsetails) constituted a very important portion of the forests and in stature often vied with the trees of today. The tree-like representatives of the groups just mentioned, unlike those of our living forests, did not reproduce by means of seeds, but entirely through the agency of those smaller and unicellular reproductive bodies known as spores. Since spores are a much less certain method of reproduction than seeds, they are formed in huge numbers, contrasting with the comparatively small production of seeds. We find the same contrast in reproduction between the lower and the higher animals. A herring will deposit from three to four million eggs in a single spring, while the domestic cow or sheep, in corresponding time, is the parent of only one or two progeny. The offspring of the higher animals are so safeguarded at every stage, that the majority are apt to survive. In the case of the millions of young herring, most fall victims to the manifold chances of their earlier existence, so that in the end relatively few escape destruction. Returning to the case of plants, furnishing the raw materials of coals, the evolution of seeds brought about a great economy in reproduction, and the huge quantities of spores produced by the older forests, were no longer present in the formation of lacustrine sediments. True, the blossom dust or pollen of the predominant seed-plants of later geological ages, mostly achieved a

watery grave, but the amount of such material is insignificant, compared with the rich and resinous harvests of the Paleozoic tree-like Ferns, Club-mosses and Calamites. Not only are the water-born harvests of more modern trees, smaller than those of

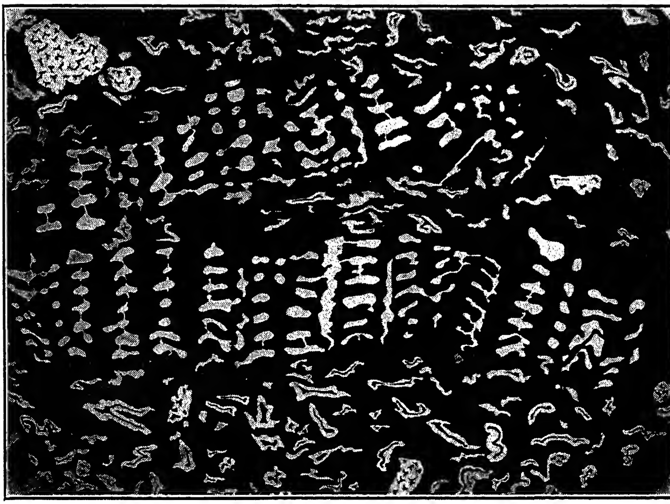

FIG. 44.—Magnified view of a vertical section of brown coal from Bohemia.

their Paleozoic predecessors, but they also lack the large content of hydrocarbons, which so enriched the lacustrine vegetal deposits of earlier geological times. It follows from the facts just described, that the later coals lack, other things being equal, the rich bituminous properties of the Paleozoic fossil fuels. The older coals consequently belong in the

same category of superlative excellence as do old wines and old friends.

The accompanying illustration will give some idea of the organization of brown coals in comparison with those described in earlier pages. Through the center run two fragments of charred wood similar to that often found in the older coals. In this instance the wood is clearly coniferous. Surrounding the charred wood but not penetrating it, is a general matrix, which in the original is light brown in color. This represents the modified ligno-cellulose, which is in general so important a constituent of the shiny or glossy older coals. The degree of chemical and physical modification, however, is much less than in the fuels of greater geological age. As in the older coals, spores are likewise present, but in smaller numbers, and these appear as light structures in the illustration. For the most part, in the coals under discussion, they are pollen-grains or blossom dust in a condition of collapse due to compression. The examination of a large number of brown or so-called lignitic coals of wide geographical occurrence, has made it clear that the essential features of organization of the later coals, are identical with those of the Paleozoic age. Such differences as exist are due to the different character of the vegetation in more recent times and not to any important differences in the essential conditions of deposition under a permanent cover of open water. In general less prolonged action of time and pres-

sure have resulted in fuels of lower grade and less high content of carbon. Likewise the proportion of oxygen and hydrogen is higher than in the older fossil fuels and the ratio of hydrogen to oxygen is also much lower, than in the coals, which in the present state of our knowledge, are most valuable.

It is probable that ultimately, the brown coals will prove to be of greater value than at present. When our existing supplies of natural petroleum and natural gas have been entirely consumed, the production of gaseous or volatile fuels, susceptible of utilization in internal combustion engines, will become an urgent practical problem. Then the brown coals will contribute their share of the raw materials to be utilized by industrial chemists for the production of new sources of power. They are, however, lacking in one important feature for such utilization. For the most part, brown coals can not, in the present state of our knowledge, be transformed into coke. This is a serious obstacle to their profitable exploitation The cause of this refractory conduct in the coking ovens, seems to be the less advanced condition of chemical metamorphosis, which the woody constituents of these coals have undergone. It has been shown in an earlier chapter that the best coking coals are those which contained originally the largest amount of lignocellulose. Outstanding examples of the truth of this assertion have been supplied by the investigation of the organization of the admirable coking coals of the Connels-

ville basin and the Pocahontas field. Although woody materials are fundamental in good coking coals, they must have reached the proper degree of carbonification, which in general is naturally much less prevalent in brown coals than it is in bituminous ones. Recent improvements in the processes of the coking industry lead to the hope, however, that sooner or later, the refractory quality of modern and low-grade coals, in the coking oven will be overcome. Whether this end will be attained by the subjection of such coals to intensive reactions, which will quickly bring them into the condition found generally in the older coals, only time will tell. They are already manipulated by mixing with other older coals or by briquetting with suitable binding media.

CHAPTER XV

THE ORIGIN AND USES OF COAL

IN the preceding chapters an account has been given of the general conditions under which the various types of coal have been produced in nature. It will serve a useful purpose to describe here the utilities of the different kinds of coal in relation to their mode of origin and structural constituents. It has been made clear in the foregoing pages that coal is the natural product, which is particularly related to our present civilization; that is to say, the present age is essentially an Age of Coal. In spite of the fact that this mineral is fundamental to the activities of our time, very little real knowledge in regard to its structure and consequent origin has in the past been available. It is a surprising condition, that even in works which deal particularly with coal, illustrations of its essential organization are conspicuous by their absence. This has not been the fault of the authors of such works, but is the consequence of the fact that very little has been known of the actual structure of this invaluable mineral. The present writer has given much attention to the study of extinct plants and in that connection has

developed methods of study for the quantities of the carbonized remains of plants, which are to be found in the strata representing the various geological ages. These remains are not only infinitely more abundant than are the petrified or mineralized parts of plants, but in general they afford to the investigator much more complete and detailed information, than do the latter. It seemed likely that modifications of methods, which revealed the structure of the charred remains of plants long extinct, might profitably be applied to that virtually unknown mineral, coal, consisting as it does of remains both charred or carbonized and also to a much greater extent, of material in the carbonified condition. This last state is the result mainly of secular water-action or hydrolysis, but its end-result, chemically although not structurally, resembles that produced by charring or carbonization.

The development of practicable methods for the investigation of coal did not prove an easy task, for although the carbonized relics in coal yielded to the methods employed successfully in the case of accumulations of the charred remains of plants, the carbonified matrix, long subject to water action, to pressure, and often to an elevated temperature, required a much modified technical manipulation for its successful study. It was only after years of experiment that the higher grade and more completely carbonified coals were mastered. The anthracites proved particularly difficult and it is only within

the past few years that the mastery of these refractory coals has been won and they have been forced to yield up the secret of their structural organization and consequent origin. A category of coals, which has likewise proved particularly difficult of manipulation, is the high grade coking coals. These unite a high content of fixed carbon with a rather tender and fragile consistency. As a consequence the chemical methods of bleaching and softening have to be considerably modified.

In an early chapter, the mode of accumulation of vegetable materials in water has been described. An accurate conception of what in general takes place in the depths of open bodies of water, of relatively constant level and surrounded by vegetation, is usually conspicuous by its absence in works specially devoted to the description of coal. It has been for example, very generally believed that the extremely perishable remains of those low water plants known as Algae, persist in the accumulations in the bottoms of lake and similar waters. It has been shown from an investigation of the lacustrine accumulations of eastern North America from Canada to Florida, that such organisms are conspicuous by their complete absence. The only exception to this statement is provided by those Algae, which have a mineralized cell-wall, namely the Diatoms and the Stoneworts or Characeæ. While affirming the persistence of such delicate structures as Algae in organic lacustrine sediments, the highly putrid

general condition of these deposits has been, surprisingly enough, strongly emphasized. One European investigator, whose views on coal deservedly command respect, Potonié, has given to the fine plastic organic material, occupying the depths of stagnant, fresh water the appellation Sapropel, thus implying the condition of extreme decay indicated above. As a matter of fact the fine deposits in lakes are not in general in a condition of decay, due to the action of micro-organisms, but with the exception of those, which like the Algae are extremely perishable, are in a surprising state of preservation, even when thousands of years old. The term Sapropel is accordingly a misnomer and its use is apparently unauthorized by the facts. The accumulations in lakes should be studied before they are unwatered, as after the removal of water by the drainage of the lakes or lagoons changes quickly result. These rapidly modify the organization of the materials and are not characteristic of the organic muck, in its natural condition, even after it has lain for thousands of years in the water-covered depths. It can not be too strongly emphasized that the presence of a permanent water cover inhibits the action of the organisms which bring about the destruction of the lignocellulose. This fact is generally recognized in the sound engineering practice of regarding wooden piles, constantly covered by water, as permanent structure. It would not be necessary to emphasize this situation, were it not so generally

disregarded by those who write on the subject of the organization of coal.

It will be clear to the reader from the statements made above, as well as in earlier pages of this volume, that the presence of a constant cover of water guarantees indefinitely the integrity of vegetable accumulations, which are not extremely perishable. It is known from the investigation of the late Dr. C. A. Davis, that in the United States the greater part of vegetable accumulations are of lacustrine origin. Only in higher latitudes, where the drying action of the sun is feeble, are vegetable accumulations formed in quantity on the unwatered surface of the ground. Such deposits constitute peat, and are in marked contrast to the much more abundant deposits of lacustrine origin, better known as muck, since the term Sapropel, for reasons indicated above, is inadmissible. Peat is constituted of plants, which have fallen where they grew, and as a consequence their dead remains are penetrated by the roots of living successors. These in turn lie prostrate and become the seed-bed of still other generations. Such deposits are termed autochthonous or *in situ* deposits and differ strikingly, both as regards their constituents and mode of formation, from the accumulations in open water, to which the term allochthonous or transport material is given. The latter contains the less perishable remains of both water plants and animals, and is, moreover, the repository of large quantities of the pollen and spores

of land-plants. These types of constituents are conspicuous by their absence in true peat. The branches, twigs, leaves, and other vegetative parts of terrestrial plants are however often abundant in aqueous deposits, which they reach through the action of the winds or of running water. From the nature of sedimentation of vegetable materials, the finer constituents, in contrast to mineral deposition, sink first, while the coarser parts float for a while before they disappear beneath the surface of the water. The twigs and branches are as a result often caught in the shallows and in general the upper layers of lacustrine deposits are much coarser than their lower ones. This condition is accentuated by wave action, which as the level of the vegetable accumulations rises, tends to wash out and remove the finer parts. This impact, the coarser parts, by their greater weight and their entangled condition, are able to resist. The binding influence of matted vegetable material is well understood, and is employed in protecting exposed shores from erosion through the action of water. Certain of the grasses and sedges commonly occurring on shores of lakes and similar bodies of water are particularly efficient in this respect, and doubtless the soil-binding bullrushes, sedges, cat-tails, grasses, irises, etc., of the strands and borders of our existing lakes had their counterpart in the vegetations of earlier geological epochs.

An equally striking contrast between the two types of accumulation, namely terrestrial peat and

lacustrine muck, is presented by their subsequent fate. In the case of aqueous deposits, the structural integrity of the material is maintained, practically as long as the water cover persists. It is only their uppermost layers, which, owing to variations of water-level, are affected by the action of the organisms destroying ligno-cellulose. Their depths are always immune from any action except the secular one of hydrolysis. This tends, in general, to soften rather than to disintegrate vegetal organization. When the lakes in the process of geological time were finally unwatered, their softened, but structurally intact contents were exposed to desiccation, pressure, and perhaps even to heat. The original deposits become compacted under these united influences, with the striking exception of the burned remains of plants, which have been swept into the waters as the sequel of conflagrations in the surrounding forests. The resulting mass is coal in various stages of elaboration, depending on the degree of action of pressure and temperature. The burned fragments constitute the so-called "mother of coal" or fusaine.

In autochthonous or *in situ* deposits, we have to do with accumulations which in general are found only in cool climates, where the sun has slight evaporative power. The conditions for the formations of such deposits are not realized in the warmer parts of the earth in the present epoch, on account of the rapid disappearance of aërial or even amphibious

vegetal accumulations under the action of wood-destroying lower organisms, which are not active where the temperature is high. The structure and distribution, as well as the affinities, of plants of those earlier geological epochs of coal formation, are such that we must assume the existence of much warmer climates than at present. Renault, the most prominent French investigator of coal, has pointed out that in the present epoch, peat formations do not extend in Europe, south of the latitude of 45, except on the mountains. Their range under the earlier often warmer climatic conditions, must have been very restricted indeed. It is true that assertions have been made that true peat-bogs occur within the tropics, but in all such cases, as have been accurately described, it is clear that the deposits represent filled up lacustrine areas, under a more or less complete forest cover. The main deposit in such cases is allochthonous and contains as a consequence large quantities of pollen. This for example is true of the formation described by Koorders and cited by Potonié, for the island of Sumatra. The peaty portion of such accumulations is superficial and of slight importance compared with the whole mass. It can accordingly have little or no significance in connection with any theories in regard to the origin of coal.

In spite of the absence of true deposits of peat in the warmer parts of the earth at the present time, it is often assumed by writers on the origin of coal,

that this valuable mineral is compacted from ordinary peat. In accordance with this view it is asserted that the organisms, which destroy ligno-cellulose, must have had a large share in the elaboration of the chemical substances found in coal. The organization of coals in general is such that they can not have been derived from terrestrial peat. Consequently the assumption that they are in general the products of changes due to the action of micro-organisms, such as are present in terrestrial peat, is without foundation. It may accordingly be stated that we have practically no coals derived from true peat. Should the world continue to grow colder, it is not impossible that at some later period, it will be possible to point to fossil fuels, which on account of favorable cool climatic conditions, have taken their origin from peat. Our actual coals have certainly not been formed in this manner to any important extent, if their internal organization is a trustworthy indication of their mode of derivation.

With the elimination of peat as a possible source of coal, and with the setting aside of the so called sapropelic hypothesis of the origin of lacustrine deposits, we are in the position to consider coals systematically in regard to their origin and industrial uses. It is commonly stated that there are two main types of coal, namely those which have a black glistening appearance and those which are characterized by a dull waxy luster. The shining or glance coals are supposed to be of terrestrial

origin, and are sometimes on that hypothesis called humic coals. The dull category of coals include the oil-shales and the cannels, and these are quite generally supposed, in contrast to the humic coals, to be of lacustrine origin, and even to be largely composed of low aquatic organisms known as Algae. This assumption however is in strong discord with their supposedly "sapropelic" origin. The distinctions described above prove to be of slight value, when subjected to the fundamental test of structure. Many glance or gleaming coals contain more remains of spores, etc., such as are characteristic of aquatic accumulations than do the dull coals, supposedly of exclusively aqueous origin. The general appearance of coals is consequently very far from being a reliable indication of their origin, composition, and consequent utility in the arts of civilization.

Dull coals in general *may* contain large quantities of spores and their general appearance definitely indicates the absence of preponderant quantities of material originally of a woody nature. They are further characterized by the unfailing presence of a matrix, much darker in hue than that presented by the spores, modified wood, and epidermal layers found in the rest of their structure. This matrix, in all probability, on the basis of our knowledge of actual deposits, is derived from the colloid materials of aquatic plants and animals. The darker hue of the matrix corresponds to the greater liability of such material to be affected by hydrolytic action.

Although the presence of a considerable proportion of spore material is usually characteristic of dull coals, they may be nearly or quite without such constituents.

The only reliable indications of the value of dull coals are supplied by microscopical and chemical analysis. The householder often for example purchases coal, which by reason of its dark hue and dull appearance is sold as cannel. The author has found that frequently in coals of this sort, the substance is mainly composed of the dark matrix and fragments of structureless wood. The spores which are an essential feature of cannel as a fuel, are often conspicuously few in number. In the case of oil-shale, the liability to error is equally great, if only the general appearance is relied upon. A large amount of mineral matter may be present, which naturally reduces the yield of the shale in oil. The dark matrix and any woody constituents, are likewise not petroliferous.

The black dull coals or cannels and the lighter colored dull coals or oil-shales, are, in spite of the limitations indicated above, particularly valuable in connection with uses which involve the abundant evolution of illuminating gases and of the hydrocarbons, collectively known as petroleum. They are not of value in other directions, such as, for example, the production of coke or for the supply of intermediates for the manufacture of anilin dyes, etc.

It is however the category of shiny or glance coals,

which in the long run will be most valuable industrially for the end of the natural supplies of oil and gas, derived from the dull-appearing constituents of coal, is clearly in sight. The distillation of oil-shales and cannels is not likely to prove even measurably profitable, compared with the exploitation of the natural product and the supplies will not only be much less abundant but also must command much higher prices than at present. The exploitation of the coals, forming much more than nine-tenths of the visible resources in fossil fuels, is the great technical problem of the future. There can be little doubt that the appropriate chemical manipulation of the glance or glistening coals, will for centuries to come, supply the human species, with those outstanding industrial advantages which are characteristic of our age.

Probably the greatest field for improvement is at present supplied by the coals of lowest grade, in which water, oxygen, and hydrogen are still largely present. The brown coals are extremely abundant and are widely distributed. As a consequence their utilization presents a problem of the greatest practical importance from the standpoint of the industrial development upon which the material welfare of modern communities rests. The great activity shown in the improvement of coking and similar processes gives promise that ere long the coals of lower grade will become only less valuable in the arts of civilization than those, which have been re-

fined and devolatilized by the slow and relatively wasteful processes of Nature.

It has been shown in the foregoing pages, that a large content of wood in the original materials of a coal, tends, other things being equal, to make it available for coking purposes. The manufacture of coke supplies a product, already basal to all the metallurgical industries, so characteristic of our age and civilization. The by-products of the manufacture of coke, although not important in volume, compared with the coke itself, are of the greatest significance from the standpoint of the highest uses. Our dyestuffs, our medicines, our antiseptics, our solvents, to an increasing extent our volatile fuels and the most powerful explosives used in modern warfare, are all products of the dry distillation of coals of the shining or glossy type. Those coals which are largely woody are the most useful from the standpoint of the winning of these invaluable materials. The finest coking coals are those which contain the largest amount of wood and which at the same time have reached by the process of time the greatest concentration of the carbon content, without at the same time having suffered loss of their volatile constituents. Excellent examples of coals complying with these requirements are supplied by the Connelsville and Pocahontas areas.

Although the purely woody coals are most useful from the standpoint of the production of metallurgical coke, coals which contain even a consider-

able amount of spores are very valuable in the coking industry. Such coals, although not of the highest grade, for the manufacture of coke, yield by-products which are compensatory. The presence of spores, for example, enriches the gaseous products of such coal and makes them suitable for the manufacture of illuminating gases. Further, the higher spore content lends a greater value to the volatile liquid products of distillation. A difficulty often encountered in glistening coals is their refractory action in the coking oven. This is generally due to the fact that the modification of the woody constituents of the coal has not gone sufficiently far under the conditions of nature. It is sometimes due however to the too great abundance of spores and dark matrix. As has been previously pointed out, coals which are predominantly composed of spores and dark hued matrix, such as oil shales and cannels, are quite incapable of being transformed into coke. Even the dull layers of coal, which are largely glistening coals, are refractory. A large content of ash likewise unfits a coal for coking utilization. Where the shortcomings of the coal are due to the insufficient chemical modification of the originally woody constituents, it is probable, that in the long run, they will be overcome, because it is found that a previous pre-heating throughout, often makes coals, otherwise refractory, utilizable for coking purposes.

Everything points to the probability that the coking industries will become more and more im-

portant. The visible supplies of anthracite are strictly limited and the day is not far off, when the use of anthracites for domestic purposes in eastern North America will be brought to an end through diminishing supplies and rising costs. When that time arrives, the needs of the householder will in all probability be largely met by the activities of the coking plants of newer type, in which a devolatilized fuel more like high grade coal is produced, through the employment of lower temperatures and more prolonged treatment, than have previously been used for such processes.

Concerning anthracite itself little need be stated. This is a category of strictly limited supply and in the long run it will not accordingly figure largely in the coal problem. Its origin seems now to be definitely cleared up and although no very large number of anthracite coals have been investigated, it seems reasonably certain that the mode of origin of this highly carbonized fossil fuel, is similar to the mass of other coals, namely aquatic or lacustrine. The Pennsylvania anthracites strongly resemble in structure the coking coals of highest grade, namely those of the Connelsville and Pocahontas fields. The only important differences between these coals and anthracites is their less content of carbon and more fragile consistency. The superior hardness and higher grade of anthracite seems to be due, mainly if not entirely, to changes appearing relatively late, in connection with mountain formation or igneous action.

CHAPTER XVI

THE DURATION OF COAL AND PETROLEUM

SINCE our age is one vitally related to the exploitation of the natural reserves of coal and petroleum, the probable duration of the supplies of these invaluable products of the earth is a subject of fundamental interest. The executive committee of the Twelfth International Geological Congress chose the all important subject of coal for its deliberations at the meeting held in Toronto, Canada, in 1913, one year before the recent World War. It is fortunate that in this connection a large body of authoritative and reliable statistics was accumulated from the whole world. Under present conditions information so comprehensive and so reliable is practically unobtainable.

The data compiled on the initiative of the executive officers of the Twelfth International Geological Congress are contained in three large quarto volumes and the statements here set down are deduced from these invaluable records. The procedure adopted by the Geological Congress was to ask for reports of the actual and also the probable resources in coal of the various continents and countries of

the world. These were tabulated under the headings of the various grades or ranks of coal, such as anthracites, bituminous coals, sub-bituminous coals, and brown coals, etc. The coals of the first rank, namely, the anthracites, are found in all three of the continental areas of the Northern Hemisphere, but in very disproportionate amounts. Asia, with about one sixth of the world's known supply of coal, for example, has one third of it in the form of anthracite, while North America (United States and Canada), which possesses over five sevenths of the world's coal, has not over one hundredth as much proportionately of this high grade fuel. In the case of the United States, one tenth of the visible supply of anthracite was already exhausted more than a decade ago. The European proportion of anthracite coals is even smaller than that of North America. It may be inferred that in the very near future, the inhabitants of the European and American continents will have to forego the use of anthracite, which will still be available for many years in continental Asia.

According to the tabulation of the total resources, furnished for the Twelfth International Geological Congress, the world has available 7,397,553 millions of millions of tons (metric tons) of coal. By far the greater portion of these resources, namely over five million millions of tons occur in North America. Asia is a poor second with 1,279,586 millions of millions of tons. Europe has 784,190 millions of

millions of tons; Australia and Oceania 170,410 millions of millions, and Africa only 57,839 millions of millions of tons.

The duration of the known supplies of coal for the world at large as worked out on the basis of the continued consumption at the rate of 1910, is six thousand five hundred years. But since the consumption in the great industrial countries, which naturally also use the greatest amounts of coal, had, in some cases, by 1922, increased nearly fifty *per cent* it follows that the total exhaustion of coal will come very much sooner than six thousand five hundred years hence. Indeed it may be doubted on the basis of reliable statistics, whether the present Age of Coal, will last as long as its predecessor, the Age of Iron. The Iron Age began in the Egyptian and Eastern Mediterranean region about one thousand years before Christ, and lasted down until about the middle of the eighteenth century after Christ, when it passed into the Age of Coal. It would be a very sanguine prophet, indeed, who would in the face of the rapidly increasing consumption of the basal mineral of our civilization, predict for it the three thousand years of the Age of Iron. As the world and its human population make progress in history, the great periods become shorter and shorter and the pace ever more rapid. The Paleolithic Age of chipped stone was apparently of almost immemorial duration, in terms of human chronology. Its successor, the Neolithic or New Stone Age was much

shorter and the Bronze Age was still more abbreviated. Of all the Ages of man which have passed into history, the Iron Age had the briefest duration. It is probable that our period, the Age of Coal, will have a still shorter course. The coal seams, accumulated through the hoardings of countless ages, will last longer than have the primeval and secular forests, which once covered Asia, Europe, and America, but their ultimate disappearance is none the less sure. The human speculative spirit, which looks before and after, may well inquire what the future holds for our race, when the coal is all mined. Perhaps our successors will be able to draw directly on the Sun for supplies of energy. There is apparently, however, no useful end to be reached by foregoing the advantages and natural resources of our age, in the interests of a remote posterity.

Strictly limited as is the duration of the supply of coal for the world at large, the end in the case of even the better provided older countries is usually much nearer. If Great Britain does not increase her consumption of coal over that of the present year, all her available stores of that mineral will be exhausted within seven hundred years. Japan has a future shorter by a hundred years, but the abundant and as yet practically undeveloped supplies of the nearer mainland of Asia, make her outlook less gloomy. Germany may carry on for between one and two thousand years. The United States, in view of a huge supply, commensurate even with a

gigantic consumption, may at the present pace of utilization, be able to continue for perhaps eight thousand years. Young and richly resourceful Canada has coal in sight for nearly a hundred thousand years, if she does not grow in population and in consequent consumption of fossil fuel. Australia may look forward to sixteen or seventeen thousand years, if her progress in population and in the industrial arts stands still. All estimates based on the present consumption, however, afford merely an unreliable approximation of the future consumption of the basal mineral of our present civilization. They are in every case probably much too optimistic.

Uncertain as the outlook of our civilization is, in regard to future supplies of its fundamental mineral coal, its future, in the case of petroleum and its invaluable products, is still more problematical and doubtful. Petroleum, in the light of the foregoing pages, must be regarded as essentially the quintessence of coal, since it is the derivative of the spores of plants long extinct. Coals which are sufficiently rich in spores to rank as typical oil-shales or cannels are relatively small in amount and do not in general constitute more than one-twentieth of mined coals. Since it is only the coals which are the richest in spores, which can profitably be distilled for hydro-carbons, even under the most favorable conditions, it follows that when our natural supplies of mineral oils or petroleum are exhausted, we shall be in desperate need of such products. The later prog-

ress of our civilization, and the development of its most effectual engines, are in fact, inseparably linked with petroleum and its derivations. Naturally as a result of this situation, petroleum plays a foremost part in the practical world politics of our times. It is precisely here that discriminating vision of the basal facts is necessary. No national policy, even narrowly utilitarian, can be founded on the exploitation of petroleum, unless the supplies of mineral oil are to have a reasonably long duration. Unfortunately a consideration of the present reserves of petroleum does not justify any great degree of optimism in regard to the future. The successful pursuit of oil has made many private fortunes, but unwise national exploitation of the petroleum resources of the world is likely to be followed by dire results for civilization.

The situation in regard to oil has recently been admirably summarized in Bacon and Hamor's *American Fuels* (New York, McGraw Hill Book Co., 1922.) It is there stated (p. 1191) that crude petroleum is being taken from the ground in the United States at the rate of four hundred million barrels *per annum*. Up to the end of 1919, about twelve times that quantity of petroleum had been drawn from the earth within the boundaries of the United States, since the first well was drilled in Titusville, Pa., in 1859. At the present rate of consumption this total of oil would be consumed in about fourteen years. These authors estimate that

if the rate of 1919 is maintained, the American supplies of oil will be completely exhausted in a quarter of a century. Long before that time there will naturally be a great shortage of the native product, and the United States will be more and more dependent on supplies brought in from other countries.

It has been variously estimated that the needs of the United States in petroleum by 1925 will be from five hundred million to over six hundred million barrels of oil. This greater consumption will naturally bring about an earlier exhaustion of the supplies derived from American wells and will hasten the dependence of the United States on the resources in oil of other countries. The peak of American production will also be reached by the quarter century mark and afterwards there will be an increasingly rapid decline of domestic production, extending perhaps into the beginning of the next century. At the present time, oil is used for many purposes which are essentially uneconomic. While there may be the excuse of necessity for using petroleum on battleships and other vessels of war, the employment of this precious and relatively scanty fuel for steam engines and in domestic heating plants is extravagant and shortsighted. The utilization of oil and its more volatile derivatives in internal combustion engines is justified by reason of the much greater efficiency of such machinery as compared with that actuated by steam.

Bacon and Hamor estimate that the future do-

mestic supply of petroleum will be wholly inadequate and suggest the following expedients for prolonging the possibility of utilization. 1. Obtaining greater supplies of crude oil, by direct importation from foreign countries, by the active development of foreign oil fields, by the establishment of industries involving the distillation of oil-shales and finally by increased recoveries from our present oil fields through more efficient methods and the elimination of wastes in production. 2. Better utilization of the available crude oil by pyrolysis or "cracking" of crude oil into gasoline, by the development of substitutes for gasoline and through the utilization of internal combustion engines of the Diesel type, burning crude or non-volatile oil.

The second category of expedients seems to be entirely without objection but in connection with the first, there are many serious difficulties. The importation of oil for example, unless from such near regions as the countries surrounding the Caribbean, involves costs of transportation, which may be too great to permit economical utilization. The exploitation and development of resources in oil of foreign countries also involve grave difficulties of a political nature. This has been very clearly realized in the case of the Mexican oil fields, where considerable international friction has been engendered through the exploitation of Mexican resources in oil by American capital and personnel. The United States as a result of such political difficul-

ties has refrained, in recent years, from the direct encouragement of its nationals in the exploitation of the oil fields of the Mexican Republic.

The expedient of distilling domestic oil shales, which are abundant in the states of Wyoming, Colorado, and Utah, is one which likewise presents difficult problems. It has been estimated for example, that if all the huge tonnage of coal at present mined in the United States were oil-shale and were distilled for its product in petroleum, the result would scarcely be equal to the present domestic production of oil from wells. The expense involved would apparently be too great to permit of the use of oil in the amount and in the ways now in vogue. In time we shall doubtless be sooner rather than later, driven to the distillation of oil rocks for the production of petroleum, and it is at least satisfactory to know that the raw materials are abundant within the limits of the United States. In Colorado alone, it is estimated, according to Bacon and Hamor, that there are beds of three feet or more in thickness capable of yielding twenty billion barrels of crude oil and two billion barrels of gasoline. These shales are richer in petroleum than are those at present exploited successfully in Scotland. The deposits in Utah and Wyoming are less well known both as regards their extent and their richness of yield in crude petroleum. The Scottish distilling industry at Broxburn depends for its success to a large extent on the considerable nitrogenous by-products resulting from the treatment

in retorts of the oil rocks. The American shales hitherto investigated are, like those of Australia, poor in nitrogenous by-products, and will consequently require the development of a special technical manipulation for their profitable exploitation. The Geological Survey of the United States, with commendable foresight, began the investigation of the economic utilization of our oil-shales as far back as 1913. As soon as crude oil reaches the price of five dollars a barrel, it is likely that the distillation of oil shales for petroleum, will become a problem of commercial importance. The numerous experiments now being carried on in this direction in a preliminary way, will doubtless then be appropriately rewarded. But the industry of distilling oil from its matrix will be one not without financial hazards, although it will be to a large extent free from the uncertainties as to supply, which at the present time, render the exploitation of petroleum by boring, so highly speculative.

It is accordingly clear that the great and even fabulous riches connected with the exploitation of that essence of coal known as petroleum, are likely quickly to take flight, beyond recall. It is further obvious that the more durable wealth stored up in our abundant deposits of coal is not eternal but has a long yet strictly limited future. The part of wisdom is accordingly to conserve and exploit with economy, those resources, which in the present state of development of human culture, are basal to national wellbeing. It is unwise and unseemly that

our species should wantonly exhaust in a short period of time, those treasures, which Nature has been very slowly storing up in the countless ages which have elapsed since the appearance of life upon our earth. It is indeed possible that the haste and wastefulness of the later progeny of life, in the destruction of its earlier slow and frugal hoardings, will in the end bring about the annihilation of life itself, upon the earth.

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